# Recovery Time of Soil and Vegetation from Historical Geophysical Exploration in Southeastern Utah

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## PROJECT SUMMARY

The purpose of this project was to document the recovery rates of soils and vegetation after historic geophysical exploration activities in different soil and vegetation types in southeastern Utah (Map 1, Project Location). We used 1:24,000 color aerial photos taken in 2001, GIS-based soils, vegetation and road/trail datasets, and geophysical vendor project line data to identify the location and age of geophysical source vehicle access tracks left by geophysical exploration activities. We then visited these track sites and applied predefined criteria (related to accuracy of disturbance dating and lack of post-project disturbance) to select certain sites for detailed sampling of soil and vegetative properties.

Findings from the historic seismic disturbance project indicate that most soil and vegetation measures in *Atriplex* (saltbush) communities recovered within 20 years, while most soil and vegetation measures in *Artemisia tridentata* (sagebrush) and *Coleogyne ramosissima* (blackbrush) communities did not recover after either 20 or 40 years. *Atriplex* grows on clay soils that have higher fertility and water-holding capacity than either the silty soils that *Artemisia* grows on or the sandy soils that *Coleogyne* grows on, which may explain the faster recovery rate of *Atriplex*. Therefore, seismic activities in *Artemisia* or *Coleogyne* communities, or on soils with low inherent fertility or water-holding capacity, resulted in greater impact than seismic activities in *Atriplex* communities on soils with higher fertility and water-holding capacity.

Other conclusions from this and our related research studies include: 1) the seismic techniques used for access to sites 20 years ago had much less impact on soils than those used 40 years ago; 2) current techniques for access to sites are similar enough to those used 20 years ago that we can expect current activities to also impact vegetation, soil stability, magnetic susceptibility, and soil compaction for over 20 years on sand and silt soil types, while recovery can occur within 20 years on clay soil types, as long as soils are dry during seismic activities; and 3) recovery of soil measures did not predict recovery of vegetation.

## INTRODUCTION

Oil and gas exploration using seismic technology is increasing at a rapid rate in the western US. The Department of Energy (DOE), in collaboration with the Bureau of Land Management (BLM), funded a national program to conduct research to help identify the impacts of seismic projects and to assist in developing sound mitigation and management information related to this activity. The specific purpose of this study, as related to the overall objectives of that program, was to examine the recovery rates of soil and vegetation resources from impacts associated with past seismic exploration activities.

## METHODS

### Track Site Selection

Locations of historic geophysical exploration projects and lines in southeastern Utah were obtained from Seismic Exchange, Inc. (SEI), a geophysical data warehousing company, with assistance from the International Geophysical Contractors Association. Seismic Exchange, Inc. estimated their data covered 65-70% of all historic seismic lines completed within the area of interest and provided use of two sets of line data: a metadata set of 10,864 project lines for all of Utah, with line location and line number data, and a second data set of 1,206 lines limited to southeastern Utah, with date, line number, line location, and energy source methods (Map 2). Based on the SEI data provided (see Table 1), it was evident that there were two periods of time where geophysical survey activities were concentrated, which allowed grouping into approximately 20-year and 40-year age classes.

There were two types of ground disturbances associated with creating seismic waves recorded on the geophones. One disturbance was from trucks used to make dynamite shotholes, and the other was from vibroseis trucks. The SEI data did not show any 40-year-old vibroseis lines available for analysis because the technology did not exist, and 20-year-old vibroseis projects were very limited in their off-road ability and primarily utilized existing roads. Therefore, we restricted our potential sample sites to those created by trucks associated with the dynamite shothole projects.

Data on the seismic receiver lines from SEI were placed in a Geographic Information Systems (GIS) Arcmap environment, which allowed the line location data to be displayed and overlain with other pertinent information. This included aerial photography, 1995 vegetation cover data from the Gap analysis program (GAP) (Homer 1995), digital soil surveys, and county road surveys. The aerial photographs were then used to visually identify the probable disturbance tracks from the source equipment along the receiver lines. Our assumption, based on typical seismic operation techniques, was that wherever physically possible, source lines paralleled receiver lines on older 2-D operations. An Order 3 soil survey map of Grand County, UT (USDA 1989) was used to determine what soil type the tracks occurred on, and the GAP vegetative cover map was used to determine the dominant vegetation. Both Grand and San Juan counties recently completed GPS inventories of all roads and trails in their respective counties, and these data were utilized to determine which geophysical lines had been turned into trails or roads; these access source tracks were dropped from further consideration.

The objective of this process was to identify potential sample points along the geophysical disturbance tracks that occurred in the 20-and 40-year-old age classes and that were free from post-project disturbance (e.g., not used as roads or trails by off-road vehicles or livestock, and that had not experienced large amounts of erosion), as that would have prevented objective comparisons. Table 1 identifies our initial analysis of potential sample sites.

| | **Age class** | |
|---|---|---|
| | **40-year** | **20-year** |
| # projects analyzed | 4 | 6 |
| Project kilometers | 2,195 | 1,050 |
| Potential sample sites identified | 123 | 92 |
| Field evaluations of potential sample sites | 58 | 78 |
| # sites determined acceptable for sampling | 26 | 28 |
| # of sites sampled | 10 | 8 |

Table 1. Data on the number of tracks examined, those selected as potential sites, and those chosen for sampling.

The aerial photo and GIS analysis identified 123 potential sample sites for lines in a 40-year age class and 92 potential sample sites for lines in a 20-year age class. We then categorized the lines into groups based on soil texture and dominant vegetation. Most sites were on silty soils that supported *Artemisia tridentata* (sagebrush), sandy soils that supported *Coleogyne ramosissima* (blackbrush), or clay soils that supported *Atriplex confertifolia/A. garrettii* (saltbush). We then visited potential sites on the three soil/vegetation types, and sites with any visible post-geophysical disturbance were dropped from further consideration. The chosen sites had similar elevation and precipitation regimes. Within these constraints, we chose three geographically separated sites each for *Artemisia*, *Coleogyne*, and *Atriplex* in two age classes (20 and 40 years), giving us a total of 18 sites (Table 2, Map 4).

| Site names | Project Name | Utm N | Utm E | Text code |
|---|---|---|---|---|
| Silty soils | | | | |
| Artemisia 20-1 | EEX-U82-135-1 | 632968 | 4242598 | Artr 20 |
| Artemisia 20-2 | EEX-U81-127-1 | 632966 | 4245502 | Artr 20 |
| Artemisia 20-3 | EEX-U81-106-2 | 632971 | 4245499 | Artr 20 |
| Artemisia 40-4 | GNN-6 | 636667 | 4243684 | Artr 40 |
| Artemisia 40-5 | GNN-18-1 | 634484 | 4240076 | Artr 40 |
| Artemisia 40-6 | GNN-18-4 | 636950 | 4237240 | Artr 40 |
| Clay soils | | | | |
| Atriplex 20-1 | 78-120-009-2 | 607524 | 4293493 | Atsp 20 |
| Atriplex 20-2 | GD-5-5-3 | 598155 | 4301270 | Atsp 20 |
| Atriplex 20-3 | GD-5-5-2 | 593775 | 4297638 | Atsp 20 |
| Atriplex 40-4 | GNK-26A-2 | 609356 | 4308941 | Atsp 40 |
| Atriplex 40-5 | GNK-26C-3 | 602061 | 4313469 | Atsp 40 |
| Atriplex 40-6 | GNK-24C-1 | 598966 | 4308774 | Atsp 40 |
| Sandy soils | | | | |
| Coleogyne 20-5 | GJF-1B-1 | 646312 | 4290503 | Cora 20 |
| Coleogyne 20-6 | 78-120-5-2 | 602583 | 4288913 | Cora 20 |
| Coleogyne 40-1 | GNK-12-1 | 623174 | 4285319 | Cora 40 |
| Coleogyne 40-2 | GNK-12-2 | 621953 | 4285690 | Cora 40 |
| Coleogyne 40-3 | GNK-12-9 | 621674 | 4286166 | Cora 40 |
| Coleogyne 40-4 | GNP-27-1 | 597807 | 4249800 | Cora 40 |

Table 2. The site names, project names, locations, and codes used in the text for each of the sampled sites. Appendix II contains a photo example of each type of sample site.

### Site measurements

At each of the 18 sites, we designated three spatially separated plots 25 m long by 10 m wide. Within each plot, we established two 20-m-long transects: one within the disturbance track and one in an adjacent area 3-5 m from the track (to avoid collateral impact from the trucks) as the control area. Therefore, we sampled a total of 54 track plots paired with 54 control areas. In total, we sampled 2,160 m of transect line. At each plot, a variety of soil and vegetation measures were taken (Table 3), described in detail below.

| General Data | Soils | Vegetation |
|---|---|---|
| Elevation | Magnetometer | Coppice size, form |
| Slope | Soil depth | Ground cover |
| Aspect | Soil stability | Lichen cover |
| Landscape position | Soil compaction | Cyanobacterial biomass |
| Vegetation type | Chlorophyll content | Shrub volume, cover |
| Soil type | Soil nutrients | Total plant cover |
| | | Plant richness |
| | | Leaf nutrients |
| | | Leaf isotopes |
| | | Number of seedlings |

Table 3. The list of variables measured along each transect at each site.

*Ground cover and plant measures*

The cover of biological soil crusts was measured using a point-hit frame (containing 20 point hits) at four places under plant canopies and at four places in plant interspaces along each transect. Therefore, we had 80 data points for under-canopy and 80 point hits for interspaces along each transect (for a total of 160 points per transect x 2 transects = 320 per plot, 960 points for each site). Chlorophyll *a* sample analysis was used to indicate cyanobacterial biomass. Along each transect, 10 soil samples (0-0.5 cm) were composited into one sample each for the track and control (thus 2 samples per plot and 6 per site). Shrub cover and the number of individual shrubs was measured using a 20-m-line transect along the track and the control in the three plots, resulting in 120 line m per site. The volume of the first 10 shrubs encountered along the line was measured (if 10 shrubs were not encountered in the first 20 m the line was extended until 10 shrubs were encountered). We collected 10 leaves off of at least five plants of the dominant species and composited them for one sample each for the track and the control (thus 2 samples per species per plot and 12 samples per species per site) to analyze for nutrients and isotopes.

*Crushed shrubs*

We also visited nine sites with one-year-old seismic truck tracks (in a separate but related research project) in order to better understand if the shrubs we saw in the 20- and 40-year-old tracks were likely survivors of the exploration activity, or whether they were seedlings that had established after the exploration activity. These recent tracks were on sandy soils. First we conducted a census of live and dead shrubs. The census start point was in a reasonably vegetated part of the track. We did this at three sites. We then tagged shrubs at those three sites, as well as at six other sites. We tagged shrubs that were alive but crushed from the seismic trucks so we could calculate long-term survival of the crushed shrubs. Transects were of variable length (20-500 m long), because we walked along the track until 10 of the dominant shrubs were encountered. We also tagged any other shrubs that occurred between the dominant shrubs. We then returned two years later and reassessed the condition and volume of the tagged shrubs (thus, three years after the seismic exploration).

*Soil measures*

We measured the dust content of soils using a magnetic susceptibility meter (this measure is a surrogate for loss of fine soil particles via erosion). We took 15 readings per transect (thus, 30 per plot and 90 per site). Soil depth was measured by pounding a sharpened probe into the ground until bedrock was reached at 5 places per transect (thus 10 per plot and 30 per site). Soil stability was measured using a field-adapted wet soil aggregate stability kit. We took 6 surface measures per transect (thus, 12 per plot and 36 per site) and 3 sub-surface measures (thus, 6 per plot and 18 per site). Soil penetration resistance was used as an indicator of compaction and was measured with an impact penetrometer on dry soils at 8 points per transect at each of 4 depths (0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm). Thus, we had 16 points per plot and 48 per site for each of the 4 depths. For soil nutrients, we collected 20 subsamples of soils (composited into one sample) for each track and control at each plot (thus, 6 samples per site). We sent these samples to the Brigham Young University Plant and Soil Analysis Laboratory to be analyzed for texture (sand fractions, silt, clay), macronutrients (phosphorus, nitrogen, potassium), organic matter, pH, cation exchange capacity, major cations (calcium, magnesium, sodium), micronutrients (zinc, iron, manganese, copper), and acid neutralizing potential (ANP, the ability of the soil to buffer acids; high ANP indicates a low availability of phosphorus to plants), using standard laboratory techniques.

*Statistical analyses and notation*

We analyzed the data using a t-test to compare tracks versus controls. We used a rank test to compare the percentile recovery between the 20- and 40-year tracks. For ease of discussion, we will refer to *Artemisia tridentata* sites as Artr, *Atriplex confertifolia* and *Atriplex garrettii* sites as Atsp, and *Coleogyne ramosissima* sites as Cora. We will refer to the 20-year-old and 40-year-old sites as Artr-20, Artr-40, Atsp-20, Atsp-40, Cora-20 and Cora-40.

## RESULTS

### Biological soil crust and plant community measures

Biological soil crust: Lichen and moss cover was extremely low at all sites measured, including the control sites, and thus there was large variability in the measured values (Fig. 1). Consequently, even though absolute recovery was very low (< 50%), many of the differences between tracks and controls were not statistically distinct. Given the very low cover and high variability, these results should be taken with caution and not used to predict recovery rates of lichens and mosses from seismic activity. Cyanobacterial biomass (cyanobacteria are an early successional part of biological soil crusts), as indicated by chlorophyll *a*, was similar in the tracks and controls in both plant interspaces and under plant canopies at all sites except Cora-40.

Plant community, physical structure: The total amount of interspace present (total % cover of bare ground between plants) and the distance between plants (interspace length) showed little recovery at the Artr-20, Artr-40, Cora-20 and Cora-40 sites (Fig. 1). (Because the seismic activity increased the amount of bare ground and the size of bare ground patches, numbers equal to or less than 100% indicate recovery). The exception to this was the Atsp community, which showed complete recovery of both these variables. Coppice volume (the size of the mound underneath shrubs) had not recovered at any site after 20 or 40 years.

Plant community, biological structure: The number of individual shrubs was 45-76% lower in the tracks than along the control transect, except for Atsp-20, where there was no significant difference (Table 4). Shrub volume was lower in the tracks than in the control at most sites, with the exception of Atsp-20 (Fig. 1). The percent cover of shrubs was also lower in the tracks for all Artr and Cora sites, but Atsp showed full recovery. However, the finding of full recovery in the *Atriplex* cover should be taken with caution, as the cover of *Atriplex* was very low (5% versus 25-29% for *Coleogyne* and *Artemisia*), and thus our sample size may have been too small to accurately detect recovery rates, as absolute recovery was only 60-80% of the control. There was no difference in species richness in any vegetation community of any age.

Plant tissue isotopes and chemistry: For both carbon and nitrogen isotopes, lower numbers mean more recovery, and small differences in the numbers are meaningful. Carbon isotopes are an indicator of plant water stress, and our results indicate that *Artemisia* plants at Artr-20 and *Coleogyne* plants at both Cora-20 and Cora-40 in the tracks were under greater water stress than the same species in the control area. There was no difference in leaf tissue carbon concentrations. Whereas we found no significant difference in nitrogen isotopes at any site, indicating a recovery of the balance between nitrogen inputs and losses, there was still a reduction in the nitrogen concentration in leaves of *Artemisia* at Artr-20 and of *Coleogyne* leaves at Cora-40.

Similarly, carbon:nitrogen ratios had not recovered in *Artemisia* plants at Artr-20 or *Coleogyne* plants at Cora-40. (As ratios in the control are expected to be lower than ratios in the tracks, values at or lower than 100% indicate recovery.) The only other differences seen in plant tissue chemistry when leaves from plants in the tracks were compared to leaves from plants in the control area was a reduction in magnesium in *Artemisia* leaves at Artr-20 and an increase in zinc in *Coleogyne* tissue at Cora-40.

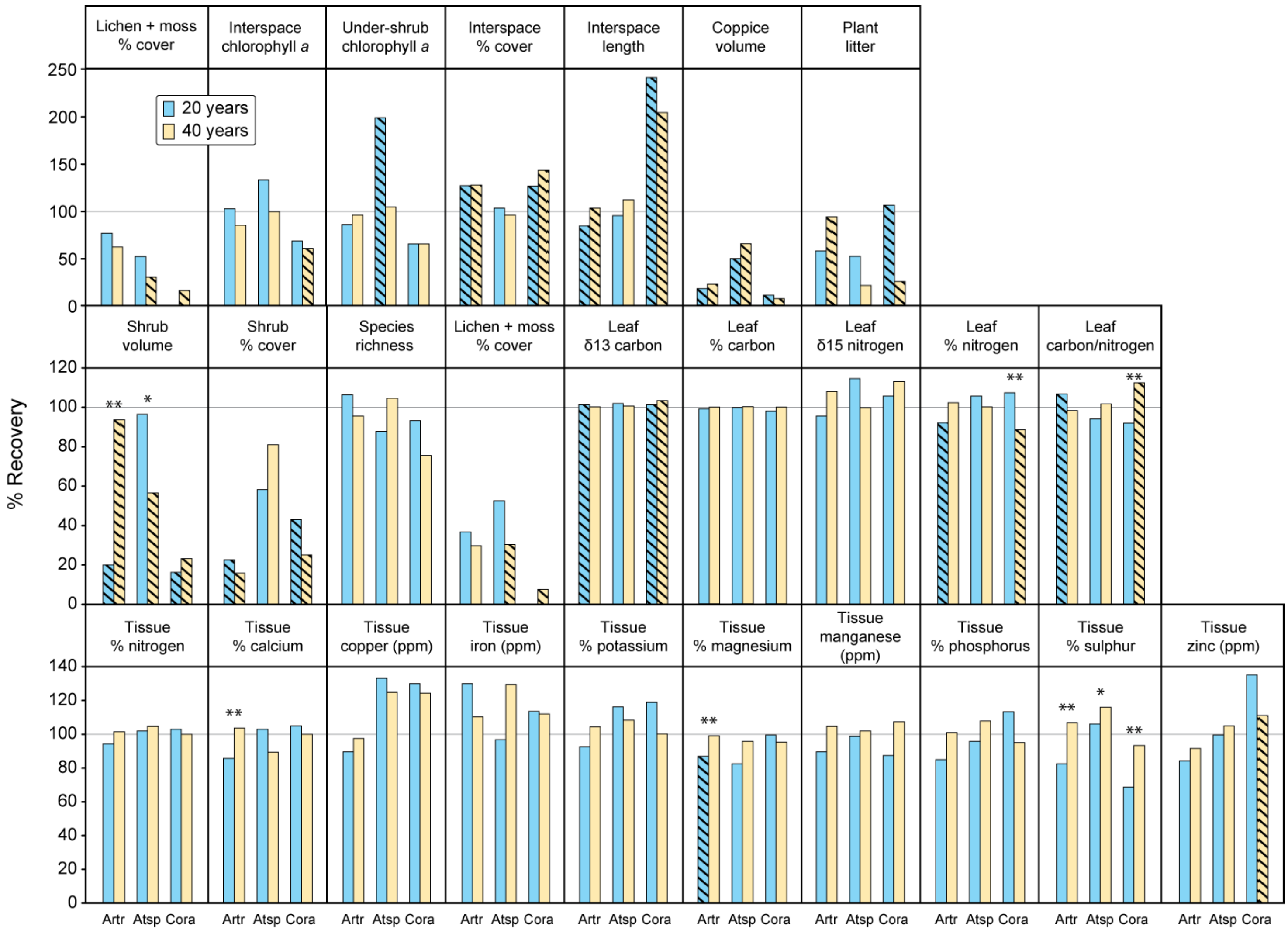


Figure 1. The percent recovery ([control-track] * 100) of biological soil crust and vegetation measures. Clear bars indicate there were no statistically significant differences between the track and control. Hatched bars indicate statistical differences at $P < 0.10$. The * indicates a difference between the 20- and 40-year-old tracks at $P < 0.10$, ** indicates $P < 0.05$.

| Species | Age | Track | | Control | | Decline | *P* |
|---|---|---|---|---|---|---|---|
| | | Mean | ± SE | Mean | ± SE | | |
| ARTR | 20 | 2.89 | ± 0.84 | 6.89 | ± 0.82 | 58% | ** |
| ARTR | 40 | 3.33 | ± 0.69 | 6.70 | ± 0.92 | 51% | ** |
| ATSP | 20 | 2.33 | ± 0.73 | 3.44 | ± 0.71 | | |
| ATSP | 40 | 2.33 | ± 0.37 | 4.33 | ± 0.73 | 47% | ** |
| CORA | 20 | 2.00 | ± 1.24 | 8.17 | ± 0.91 | 76% | ** |
| CORA | 40 | 3.55 | ± 0.89 | 6.42 | ± 1.14 | 45% | * |

Table 4. The number of individual shrubs found in the tracks and controls at each of the vegetation/soil types. The * indicates a difference between the 20- and 40-year-old tracks at $P < 0.10$, ** indicates $P < 0.05$.

**Soil measures** (Figs. 2-4)

Aggregate stability: Aggregate stability of soils at the soil surface showed full recovery in the tracks at the Artr-20 and Atsp-20 sites, while showing no recovery at the Cora-20 and all three 40-year-old sites. Subsurface aggregate stability had not recovered at Artr-20 or Atsp-20 sites, but had recovered at all other sites.

Magnetic susceptibility: Magnetic susceptibility (MS) had recovered at both Atsp-20 and Atsp-40 sites. Artr-20 still showed a reduction in MS, as did Cora-40. Artr-40 and Cora-20 had recovered.

Soil depth: Most sites had not recovered in terms of soil depth, with the exception of Artr-20.

Soil penetration resistance (compaction): At 0-5 cm, four of the sites had recovered (Artr-20, Atsp-40, and both Cora-20 and Cora-40). (Note: Higher soil resistance indicates greater compaction and thus less recovery; therefore, values over 100% indicate non-recovery.) At 5-10 cm, the two Artr sites had recovered, as well as Cora-20. Neither Atsp site had recovered, nor had Cora-40. At 10-15 cm, all 20-year-old sites had recovered, while only one 40-year-old site had recovered (Artr-40). At 15-20 cm, all three 20-year-old sites had recovered, whereas none of the 40-year sites showed recovery.

Rock cover: Rock cover was highly variable, and thus large differences between the track and control sites were often not statistically distinct. The only statistical differences were seen at Artr-20, where there was a slight decrease in rock cover in the tracks, and at Atsp-40, where there was a large increase in rock cover in the tracks.

Soil chemistry (0-0.5 cm): As with plant tissue chemistry, there were few significant differences between track and control sites. Differences were seen at the Artr-20 sites, as phosphorus, potassium, ammonium, and manganese were lower in the tracks than in the control. At Cora-40, potassium, sodium, and total nitrogen were lower in the tracks than in the control sites. Total nitrogen was also lower at Cora-20. There were also only a few differences when recovery between the 20- and 40-year-old sites within a vegetation type was compared. There was greater recovery in organic matter, very fine sand, iron, and manganese at Atsp-20 than at Atsp-40. At Artr-40, there was greater recovery of pH than at Artr-20, whereas there was greater recovery of very fine sands at Artr-20 compared to Artr-40.

Soil chemistry (0-10 cm): As with surface soil chemistry, there were only a few differences between track sites and controls. Artr-20 showed reductions in total nitrogen, very coarse sand, coarse sand, and manganese ratios in the tracks compared to the control. Artr-40 showed a decrease in sodium in the tracks. Atsp-20 showed an increase in CEC, acid neutralizing potential (ANP), medium sand, and copper in the tracks compared to the controls, and no differences were seen at Atsp-40 sites. Cora-20 showed an increase in potassium and nitrate, and Cora-40 showed an increase in total nitrogen and zinc in the tracks compared to the controls. Among ages within a vegetation group, differences were seen in Artr phosphorus, nitrogen, silt, and coarse sand. Differences in Atsp ages included total nitrogen, potassium, CEC, coarse sand, medium sand, and fine sand. Cora showed differences in total nitrogen and potassium.

As was expected, Artr sites were higher in silt than the Cora sites, Cora was higher in sand than the other two sites, and Atsp was higher in clay and silt than the other two sites (Table 5). Also as expected, all plant macro-nutrients (except phosphorus) and organic matter were higher in the clay soil than in the sandy or silty soils.

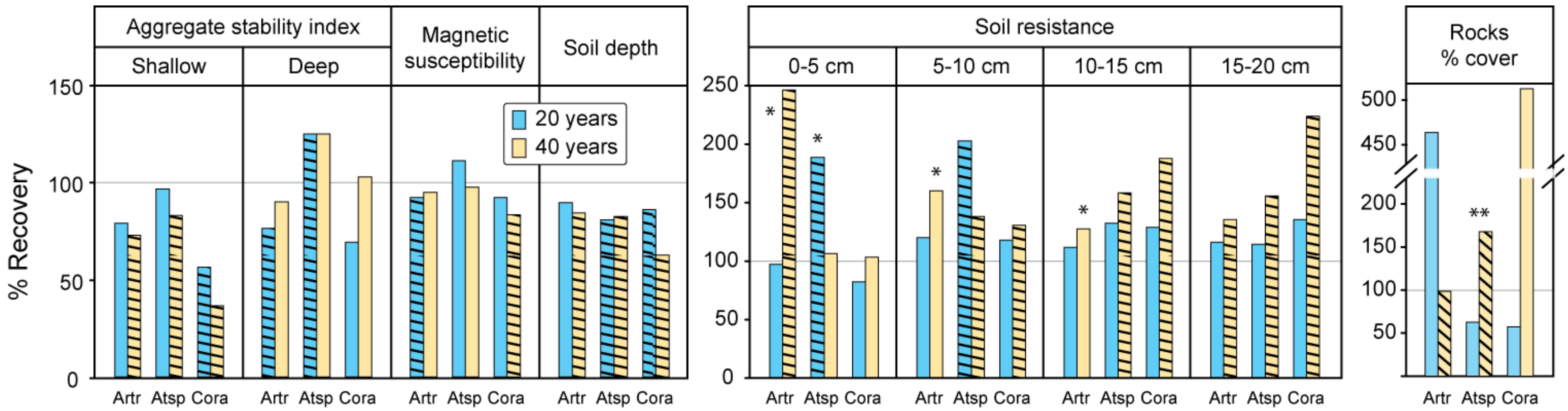


Figure 2. The percent recovery ([control-track] * 100) of physical soil measures. Clear bars indicate there were no statistically significant differences between the track and control. Hatched bars indicate statistical differences at $P < 0.10$. The * indicates a difference between the 20- and 40-year-old tracks at $P < 0.10$, ** indicates $P < 0.05$.

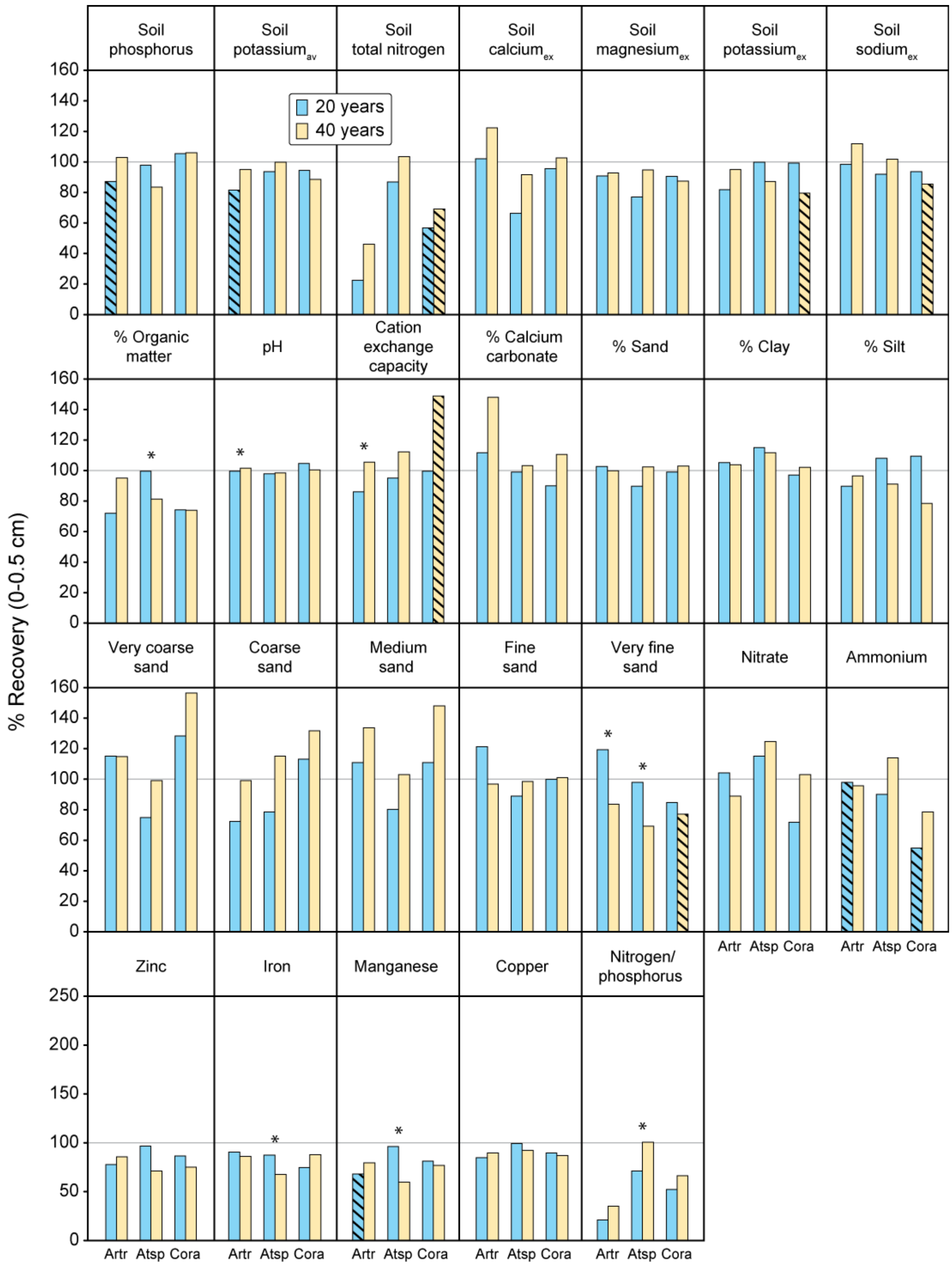


Figure 3. The percent recovery ([control-track] * 100) of soil surface chemistry (0-0.5 cm in depth). Clear bars indicate there were no statistically significant differences between the track and control. Hatched bars indicate statistical differences at $P < 0.10$. The * indicates a difference between the 20- and 40-year-old tracks at $P < 0.10$, ** indicates $P < 0.05$.

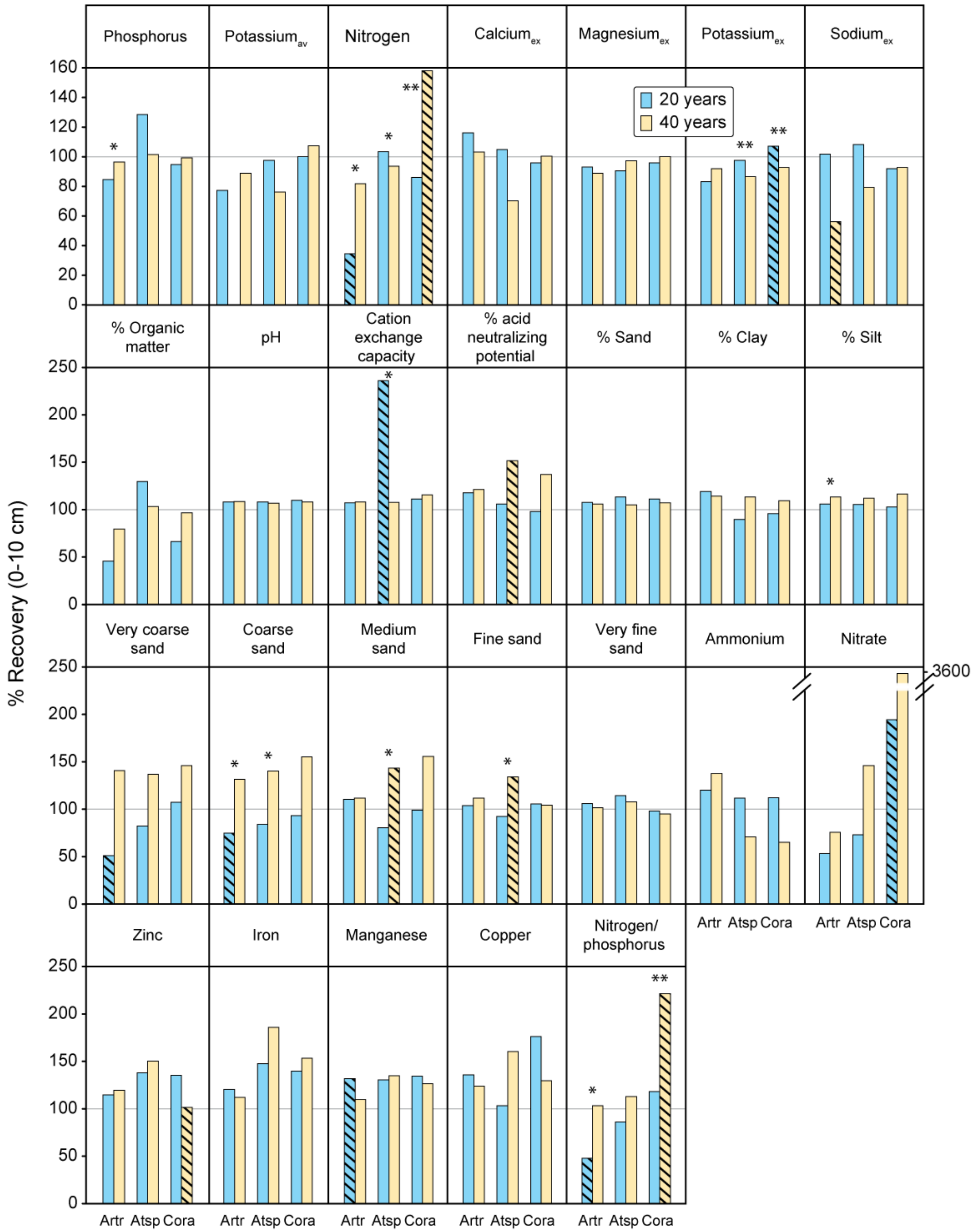


Figure 4. The percent recovery ([control-track] * 100) of soil chemistry (0-10 cm in depth). Clear bars indicate there were no statistically significant differences between the track and control. Hatched bars indicate statistical differences at $P < 0.10$. The * indicates a difference between the 20- and 40-year-old tracks at $P < 0.10$; ** indicates $P < 0.05$.

| | Site type | Mean ± SE | | Site type | Mean ± SE |
|---|---|---|---|---|---|
| P (ppm) | Artr | 10.3 ± 0.68 | $K_{ex}$ (ppm) | Artr | 156 ± 8.87$^{b}$ |
| | Atsp | 10.5 ± 0.89 | | Atsp | 195 ± 9.50$^{c}$ |
| | Cora | 9.24 ± 0.95 | | Cora | 97.8 ± 5.96$^{a}$ |
| OM (%) | Artr | 1.29 ± 0.30$^{b}$ | $Na_{ex}$ (ppm) | Artr | 50.3 ± 3.78$^{a}$ |
| | Atsp | 1.41 ± 0.11$^{b}$ | | Atsp | 172 ± 19.4$^{b}$ |
| | Cora | 0.63 ± 0.14$^{a}$ | | Cora | 57 ± 2.91$^{a}$ |
| $Ca_{ex}$ (ppm) | Artr | 1819 ± 167$^{a}$ | Total N (ppm) | Artr | 166 ± 30.8$^{ab}$ |
| | Atsp | 10515 ± 3043$^{b}$ | | Atsp | 213 ± 32.5$^{b}$ |
| | Cora | 2300 ± 88.9$^{a}$ | | Cora | 96.5 ± 20.3$^{a}$ |
| $Mg_{ex}$ (ppm) | Artr | 173 ± 9.52$^{b}$ | Sand (%) | Artr | 68.1 ± 1.62$^{b}$ |
| | Atsp | 183 ± 10.6$^{b}$ | | Atsp | 52.8 ± 2.76$^{a}$ |
| | Cora | 78.2 ± 5.92$^{a}$ | | Cora | 76.7 ± 1.72$^{c}$ |
| $K_{ex}$ (ppm) | Artr | 156 ± 8.87$^{b}$ | Clay (%) | Artr | 11.8 ± 0.53$^{a}$ |
| | Atsp | 195 ± 9.50$^{c}$ | | Atsp | 15.1 ± 1.64$^{b}$ |
| | Cora | 97.8 ± 5.96$^{a}$ | | Cora | 11.8 ± 0.54$^{a}$ |
| $Na_{ex}$ (ppm) | Artr | 50.3 ± 3.78$^{a}$ | Silt (%) | Artr | 20.0 ± 1.29$^{b}$ |
| | Atsp | 172 ± 19.4$^{b}$ | | Atsp | 29.8 ± 12.4$^{c}$ |
| | Cora | 57 ± 2.91$^{a}$ | | Cora | 11.5 ± 1.47$^{a}$ |

Table 5. Comparison of soil texture and major plant nutrients at the three site types.

## DISCUSSION

### Biological soil crust measures

As lichen and moss cover was so low in the controls at all sites, there is little to conclude from our data regarding recovery of these organisms. Cyanobacteria, in contrast, appeared to be fully recovered within 20 years at the silt and clay sites and at the sandy Cora sites except in the interspaces. This finding is supported by other studies that show more rapid recovery of cyanobacteria in finer-textured soils (Belnap and Eldridge 2003) and more rapid recovery under plant canopies than in plant interspaces (Belnap and Warren 2002). Cyanobacteria are important for soil stability, and thus their recovery is critical for reducing soil erosion.

**Plant community measures**

The *Atriplex* sites appear better able to recover from track impacts than the *Artemisia* or *Coleogyne* sites. At the *Atriplex* sites, the amount and size of shrub interspaces were the same in the tracks and the control. The number of individual shrubs, shrub cover, and shrub volume did not differ between the tracks and the control after 20 years. [However the low (5%) cover in the community may have precluded us finding significant differences between the tracks and control with our sample techniques, and thus this finding should be regarded cautiously.] The 40-year-old track sites showed low recovery rates in all soil and plant measures, probably due to blading, heavier drill rigs, or other techniques used in earlier times.

*Artemisia* showed quite low recruitment into the tracks, as evidenced by the fact that the number of individuals was 51-58% lower in the track after both 20 and 40 years. Shrub cover was also still much lower. However, the shrubs that were able to establish grew well during the 40 years after disturbance. The very small *Artemisia* found at the Artr-20 sites may indicate that the last 20 years have not been as favorable for *Artemisia* establishment or growth as the previous 20 years.

Recovery of *Coleogyne* was similar to that of *Artemisia*, in that it has been extremely slow. The number of individual shrubs present and their cover and volume, at both the 20- and 40-year-old sites, was much lower in the tracks than in the control. There was more space, and the spaces were much larger, in the tracks compared to the control. The few plants that have established were growing at a very slow rate, as evidenced by low shrub volume. Establishment and growth rates appear fairly constant when the last 20 years are compared to the previous 20 years, as there is no significant difference in shrub cover or volume between the 20- and 40-year sites. This is not a surprise, as *Coleogyne* is well known to have a very slow growth rate (Bowns and West 1976).

Carbon isotopic ratios of plant leaf tissues can indicate plant water stress, and may at least partially explain the patterns seen in shrub cover and volume. *Atriplex* plants in both the Atsp-20 and Atsp-40 sites showed no difference in leaf tissue carbon isotopes when the tracks and controls were compared, indicating the plants growing in the tracks were not under any more water stress than those growing in the control. In contrast, *Artemisia* plants at Artr-20 and *Coleogyne* plants at both Cora-20 and Cora-40 sites showed lower carbon isotopic ratios when growing in the tracks than when growing in the controls, which likely indicates that plants in the tracks were under greater water stress. This is supported by the lower shrub cover and volume at these sites as well. *Atriplex* is a plant that grows at sites with greatly reduced water availability and may be better able to handle soil conditions that restrict water availability, such as high salinity levels. The soils at the Atsp sites also have greater water-holding capacity. Leaf tissue nitrogen was also reduced at the Artr-20 and Cora-40 track plots, whereas there was full recovery at the Atsp sites, which may help explain reduced *Artemisia* and *Coleogyne* performance relative to *Atriplex*. In addition, the soils at the Atsp sites were more fertile than those at the Artr and Cora sites, as they had higher levels of all plant macronutrients and organic matter, with the exception of phosphorus.

## Soil measures

### *Soil physical measures*

We found that, unlike the plant measures, there was great variability in the response of the physical soil measures (Fig. 2), and the measures at the 40-year sites were not consistently closer to recovery than those at the 20-year-old sites, as would be expected. This is most likely due to either 1) the large amount of variability that could occur among the track sites in terms of soil type, climate, and soil conditions when the seismic tracks were made or 2) more likely, differences in truck type, weight, tires, etc., or blading with bulldozers, which once generally accompanied seismic work.

There were some interesting things to learn from these data:

First, soil texture was not as important as we thought it would be in determining the recovery rates of the soil measures, as there was little consistent response among the different measures within a soil type.

Second, specific site characteristics (either current characteristics or those present at the time of the seismic truck impacts, including exploration equipment and techniques used) appear more important than time in determining recovery rates of abiotic factors, as there were numerous examples across soil types where 40-year-old tracks had not recovered, but 20-year tracks had. This was especially true for compaction at depth (> 5 cm). This most likely indicates that techniques used for seismic exploration 40 years ago resulted in much more compaction than techniques employed 20 years ago.

Third, as the techniques to access sites used 20 years ago are similar to those used today, we can expect to see recovery of surface soil stability within 20 years at silty (Artr) and clay (Atsp) sites, but not at sandy (Cora) sites. Recovery of deep aggregate structure, however, is the opposite, with 20 years sufficient for recovery of sandy soils but not for recovery of silty or clay soils. The recovery of magnetic susceptibility takes longer than 20 years for silty sites, and soil depth takes longer than 20 years at both clay and sandy sites. Compaction appears to recover on all soil types and depths within 20 years, except for the top 10 cm on clay sites.

Fourth, among the soil factors measured, soil depth was the slowest soil measure to recover. This would indicate that soils are still being lost from these sites at an accelerated rate, an indication of residual compaction, or a possible result of blading. Regardless, as soil formation or capture is a very slow process, any of these factors would explain this result. For the 40-year-old tracks, which showed slow recovery of soil surface aggregate stability, and thus would be subjected to increased erosion, both factors are likely responsible for lack of recovery in soil depth. For the 20-year-old Artr and Atsp sites, however, aggregate stability has returned, and thus current soil erosion is likely minimal and lack of recovery is likely the result of topsoil being lost during the initial disturbance.

Fifth, although shrub volume and cover have not recovered in either age class of the Artr and Cora communities, and have recovered at the Atsp sites, there is no consistent pattern in physical soil measures to explain these results.

*Soil chemistry measures*

Although there were some differences in soil chemistry between the different site age classes, the differences were limited to a few soil elements, none of which were plant macronutrients. Differences between the track and control sites were generally small, with a few exceptions at a few sites. In addition, none of the patterns in these elements explained the faster recovery of *Atriplex* relative to *Artemisia* and *Coleogyne*.

## CONCLUSIONS

1. Most soil and vegetation measures in *Atriplex* communities appeared to have recovered within 20 years (although the finding of recovered shrub cover should be viewed with caution, as discussed above), but not in 40 years, likely indicating a difference in techniques 20 and 40 years ago. In contrast, most soil and vegetation measures in *Artemisia* and *Coleogyne* communities did not recover after either 20 or 40 years.

2. Therefore, seismic activities in *Artemisia* or *Coleogyne* communities, or on soils with low inherent water-holding capacity or fertility, have greater lasting impact than those in *Atriplex* communities or on clay soils, under the conditions during these seismic activities.

3. Access techniques used 20 years ago have much less impact on soils than those used 40 years ago. Because current access techniques are similar to those employed 20 years ago, we can expect current activities to impact vegetation, soil stability, magnetic susceptibility, and compaction for over 20 years on sand and silt soil types, and recovery of these characteristics within 20 years on clay soil types as long as soils are dry during seismic activities.

4) Recovery rates of soil measures did not predict recovery rates of vegetation.


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## Appendix I.

**Soil measures**

| **Artemisia** | | **20-year sites** | | | **40-year sites** | | |
|---|---|---|---|---|---|---|---|
| | | **ATSP1** | **ATSP2** | **ATSP3** | **ATSP4** | **ATSP5** | **ATSP6** |
| | | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** |
| Slake shallow | control | 1.00 ± 0.00 | 3.61 ± 0.47 | 3.28 ± 0.51 | 1.94 ± 0.19 | 3.28 ± 0.56 | 1.78 ± 0.29 |
| | track | 1.00 ± 0.00 | 3.17 ± 0.52 | 2.06 ± 0.44 | 1.61 ± 0.18 | 1.78 ± 0.34 | 1.72 ± 0.37 |
| Slake deep | control | 1.00 ± 0.00 | 1.00 ± 0.00 | 1.33 ± 0.24 | 1.33 ± 0.24 | 1.00 ± 0.00 | 1.00 ± 0.00 |
| | track | 1.00 ± 0.00 | 1.00 ± 0.00 | 0.56 ± 0.34 | 1.00 ± 0.24 | 1.00 ± 0.00 | 1.00 ± 0.00 |
| Species richness | control | 8.75 ± 0.95 | 8.25 ± 1.44 | 12.7 ± 1.45 | 13.7 ± 0.67 | 5.00 ± 1.53 | 5.33 ± 0.67 |
| | track | 9.25 ± 2.25 | 8.75 ± 2.06 | 13.7 ± 2.40 | 9.00 ± 1.15 | 6.33 ± 1.20 | 7.67 ± 0.33 |
| Interspace chlorophyll *a* | control | 1.04 ± 0.10 | 1.98 ± 0.12 | 2.47 ± 0.12 | 1.27 ± 0.01 | 1.26 ± 0.37 | 2.26 ± 0.28 |
| (µg chl a/g soil) | track | 1.20 ± 0.20 | 1.82 ± 0.31 | 2.31 ± 0.36 | 1.11 ± 0.15 | 1.44 ± 0.15 | 1.56 ± 0.17 |
| Undershrub chlorophyll *a* | control | 1.47 ± 0.11 | 1.82 ± 0.22 | 3.27 ± 0.81 | 1.60 ± 0.15 | 1.90 ± 0.26 | 2.20 ± 0.23 |
| (µg chl a/g soil) | track | 1.22 ± 0.12 | 1.71 ± 0.14 | 2.95 ± 0.13 | 1.07 ± 0.17 | 1.77 ± 0.47 | 2.34 ± 0.77 |
| Interspace length (m) | control | 0.70 ± 0.08 | 0.74 ± 0.11 | 0.52 ± 0.05 | 0.49 ± 0.05 | 0.50 ± 0.07 | 0.38 ± 0.03 |
| | track | 0.59 ± 0.09 | 0.73 ± 0.08 | 0.40 ± 0.04 | 0.61 ± 0.06 | 0.57 ± 0.07 | 0.31 ± 0.03 |
| Interspace cover (%) | control | 3.50 ± 0.39 | 3.69 ± 0.53 | 2.59 ± 0.23 | 2.44 ± 0.23 | 2.51 ± 0.35 | 1.91 ± 0.14 |
| | track | 2.95 ± 0.47 | 3.65 ± 0.40 | 2.00 ± 0.20 | 3.05 ± 0.32 | 2.85 ± 0.37 | 1.54 ± 0.16 |
| Coppice volume (m3) | control | 0.47 ± 0.25 | 0.07 ± 0.01 | 0.20 ± 0.03 | 0.15 ± 0.05 | 0.09 ± 0.02 | |
| | track | 0.09 ± 0.02 | 0.01 ± 0.00 | 0.02 ± 0.00 | . . | 0.03 ± 0.01 | |
| Soil depth (cm) | control | 41.5 ± 5.46 | 45.1 ± 3.34 | 37.5 ± 3.63 | 10.8 ± 1.56 | 35.8 ± 1.77 | 51.1 ± 13.9 |
| | track | 33.3 ± 5.28 | 36.1 ± 2.40 | 41.9 ± 6.26 | 5.98 ± 0.47 | 30.1 ± 1.56 | 47.8 ± 16.2 |
| Soil resistance 0-5 cm | control | 1.21 ± 0.33 | 0.52 ± 0.10 | 3.17 ± 0.53 | 3.20 ± 0.42 | 1.73 ± 0.25 | 2.12 ± 0.34 |
| (J/cm) | track | 1.16 ± 0.17 | 0.57 ± 0.09 | 3.04 ± 0.39 | 13.4 ± 1.48 | 2.03 ± 0.22 | 2.48 ± 0.29 |
| Soil resistance 5-10 cm | control | 7.77 ± 0.76 | 6.17 ± 0.68 | 18.7 ± 1.56 | 19.1 ± 1.43 | 9.42 ± 2.61 | 8.58 ± 1.13 |
| (J/cm) | track | 9.57 ± 0.97 | 7.40 ± 0.79 | 22.2 ± 3.00 | 66.2 ± 6.63 | 8.98 ± 1.06 | 9.02 ± 0.82 |
| Soil resistance 10-15 cm | control | 21.3 ± 1.72 | 17.8 ± 1.61 | 45.4 ± 2.83 | 45.9 ± 2.63 | 15.6 ± 1.25 | 16.6 ± 1.86 |
| (J/cm) | track | 23.2 ± 1.75 | 17.4 ± 2.42 | 50.0 ± 5.39 | 113 ± 22.8 | 21.2 ± 1.85 | 20.1 ± 1.57 |
| Soil resistance 15-20 cm | control | 37.7 ± 3.80 | 29.2 ± 1.87 | 66.0 ± 3.64 | 69.9 ± 5.38 | 27.0 ± 2.07 | 24.7 ± 2.46 |
| (J/cm) | track | 34.6 ± 2.83 | 26.7 ± 4.47 | 77.6 ± 8.72 | 148 ± 26.9 | 42.7 ± 3.51 | 33.7 ± 3.08 |
| Magnetometer | control | 0.16 ± 0.00 | 0.22 ± 0.01 | 0.20 ± 0.01 | 0.15 ± 0.00 | 0.21 ± 0.01 | 0.19 ± 0.01 |
| | track | 0.14 ± 0.00 | 0.20 ± 0.01 | 0.19 ± 0.00 | 0.12 ± 0.01 | 0.22 ± 0.01 | 0.18 ± 0.01 |
| Shrub volume (m3) | control | 0.92 ± 0.17 | 0.57 ± 0.08 | 1.08 ± 0.21 | 0.53 ± 0.15 | 0.65 ± 0.08 | 0.90 ± 0.18 |
| | track | 0.20 ± 0.06 | 0.10 ± 0.02 | 0.18 ± 0.04 | . . | 0.69 ± 0.55 | 0.41 ± 0.40 |
| Shrub cover (%) | control | 33.3 ± 7.39 | 25.6 ± 6.02 | 28.9 ± 7.34 | 20.6 ± 3.97 | 21.0 ± 21.00 | 21.7 ± 4.84 |
| | track | 10.5 ± 3.00 | 4.42 ± 2.66 | 5.45 ± 2.51 | 5.13 ± 1.97 | 0.00 ± 0.00 | 5.00 ± 1.96 |
| Lichen + moss cover (%) | control | 0.83 ± 0.83 | 0.42 ± 0.42 | 12.7 ± 6.22 | 0.00 ± 0.00 | 1.67 ± 1.67 | 0.83 ± 0.83 |
| | track | 0.00 ± 0.00 | 1.36 ± 0.70 | 3.75 ± 2.89 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.83 ± 0.83 |
| Rock cover (%) | control | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.79 ± 0.54 | 2.78 ± 1.87 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | track | 1.92 ± 1.92 | 0.00 ± 0.00 | 1.67 ± 1.67 | 4.61 ± 2.04 | 0.40 ± 0.40 | 1.19 ± 1.19 |
| Litter cover (%) | control | 2.08 ± 1.68 | 0.00 ± 0.00 | 4.56 ± 1.68 | 2.92 ± 1.14 | 3.75 ± 1.75 | 10.8 ± 2.81 |
| | track | 0.44 ± 0.44 | 0.91 ± 0.61 | 2.50 ± 1.31 | 0.83 ± 0.56 | 3.75 ± 1.75 | 4.58 ± 1.30 |

**Soil measures**

| Atriplex | | 20-year sites | | | 40-year sites | | |
|---|---|---|---|---|---|---|---|
| | | ARTR1 | ARTR2 | ARTR3 | ARTR4 | ARTR5 | ARTR6 |
| | | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE |
| Slake shallow | control | 3.28 ± 0.37 | 3.83 ± 0.44 | 4.17 ± 0.48 | 5.61 ± 0.28 | 4.35 ± 0.49 | 5.67 ± 0.28 |
| | track | 2.41 ± 0.48 | 4.39 ± 0.50 | 4.06 ± 0.46 | 4.11 ± 0.35 | 3.50 ± 0.53 | 5.44 ± 0.32 |
| Slake deep | control | 2.22 ± 0.43 | 1.67 ± 0.29 | 1.00 ± 0.00 | 1.44 ± 0.44 | 1.00 ± 0.00 | 1.56 ± 0.29 |
| | track | 1.11 ± 0.11 | 1.11 ± 0.11 | 1.11 ± 0.11 | 1.22 ± 0.15 | 1.22 ± 0.28 | 2.56 ± 0.71 |
| Species richness | control | 5.33 ± 0.88 | 5.00 ± 0.00 | 6.33 ± 0.33 | 5.33 ± 1.33 | 4.67 ± 0.33 | 3.67 ± 1.76 |
| | track | 4.33 ± 0.88 | 5.00 ± 0.00 | 5.33 ± 0.67 | 4.67 ± 0.88 | 4.33 ± 0.33 | 5.33 ± 0.88 |
| Interspace chlorophyll *a* | control | 1.44 ± 0.43 | 8.30 ± 1.72 | 2.34 ± 0.32 | 2.36 ± 0.51 | 2.36 ± 0.21 | 2.90 ± 0.04 |
| (µg chl a/g soil) | track | 1.42 ± 0.31 | 12.0 ± 2.20 | 2.05 ± 0.28 | 2.11 ± 0.28 | 2.33 ± 0.37 | 3.21 ± 0.77 |
| Undershrub chlorophyll *a* | control | 1.72 ± 0.24 | 3.77 ± 0.20 | 2.48 ± 0.60 | 3.20 ± 0.25 | 2.74 ± 0.24 | 4.72 ± 0.70 |
| (µg chl a/g soil) | track | 1.82 ± 0.29 | 9.64 ± 1.17 | 2.49 ± 1.06 | 3.70 ± 0.91 | 4.21 ± 1.26 | 3.28 ± 1.34 |
| Interspace length (m) | control | 1.29 ± 0.19 | 3.10 ± 0.69 | 1.16 ± 0.17 | 0.70 ± 0.07 | 0.95 ± 0.13 | 2.76 ± 0.94 |
| | track | 1.48 ± 0.22 | 1.54 ± 0.35 | 1.41 ± 0.24 | 0.82 ± 0.09 | 1.68 ± 0.30 | 1.79 ± 0.30 |
| Interspace cover (%) | control | 6.47 ± 0.97 | 15.5 ± 3.45 | 5.78 ± 0.84 | 3.51 ± 0.33 | 4.73 ± 0.67 | 13.8 ± 4.70 |
| | track | 7.41 ± 1.11 | 7.69 ± 1.74 | 7.06 ± 1.22 | 4.11 ± 0.45 | 8.41 ± 1.50 | 8.97 ± 1.49 |
| Coppice volume (m3) | control | 0.00 ± 0.00 | 0.01 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.00 | 0.01 ± 0.00 | 0.00 ± 0.00 |
| | track | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.00 | 0.01 ± 0.00 | 0.00 ± 0.00 |
| Soil depth (cm) | control | 38.8 ± 3.42 | 25.50 ± 2.41 | 34.3 ± 3.08 | 17.9 ± 1.66 | 30.67 ± 2.45 | 23.5 ± 1.52 |
| | track | 17.8 ± 1.36 | 21.33 ± 3.05 | 40.3 ± 3.76 | 10.4 ± 0.72 | 30.2 ± 2.17 | 18.8 ± 1.65 |
| Soil resistance 0-5 cm | control | 1.75 ± 0.23 | 8.40 ± 0.87 | 1.28 ± 0.20 | 4.68 ± 1.09 | 3.52 ± 0.38 | 6.58 ± 1.07 |
| (J/cm) | track | 3.50 ± 0.51 | 13.2 ± 0.83 | 5.23 ± 0.88 | 5.10 ± 0.36 | 2.91 ± 0.26 | 7.90 ± 1.79 |
| Soil resistance 5-10 cm | control | 25.9 ± 1.68 | 20.4 ± 1.30 | 8.93 ± 0.76 | 14.6 ± 1.91 | 10.3 ± 1.33 | 16.8 ± 2.24 |
| (J/cm) | track | 80.5 ± 7.84 | 27.2 ± 1.36 | 15.0 ± 1.83 | 29.9 ± 2.81 | 8.36 ± 0.80 | 20.8 ± 3.20 |
| Soil resistance 10-15 cm | control | 60.1 ± 4.35 | 27.7 ± 1.59 | 11.6 ± 1.08 | 30.5 ± 3.66 | 23.8 ± 3.60 | 28.0 ± 2.39 |
| (J/cm) | track | 166 ± 68.8 | 60.7 ± 6.97 | 14.4 ± 1.45 | 79.3 ± 7.42 | 16.0 ± 1.92 | 40.2 ± 3.98 |
| Soil resistance 15-20 cm | control | 113 ± 7.96 | 30.1 ± 1.98 | 12.6 ± 1.18 | 50.7 ± 3.85 | 44.5 ± 6.98 | 33.9 ± 2.60 |
| (J/cm) | track | 149 ± . | 91.3 ± 9.09 | 15.4 ± 1.38 | 104 ± 10.4 | 40.8 ± 5.75 | 62.6 ± 7.81 |
| Magnetometer | control | 0.09 ± 0.00 | 0.09 ± 0.00 | 0.11 ± 0.02 | 0.17 ± 0.00 | 0.13 ± 0.01 | 0.14 ± 0.01 |
| | track | 0.10 ± 0.00 | 0.08 ± 0.00 | 0.14 ± 0.03 | 0.17 ± 0.01 | 0.13 ± 0.01 | 0.13 ± 0.00 |
| Shrub volume (m3) | control | 0.01 ± 0.00 | 0.02 ± 0.00 | 0.00 ± 0.00 | 0.08 ± 0.01 | 0.03 ± 0.00 | 0.01 ± 0.00 |
| | track | 0.01 ± 0.00 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.05 ± 0.01 | 0.02 ± 0.00 | 0.00 ± 0.00 |
| Shrub cover (%) | control | 7.30 ± 3.13 | 4.33 ± 1.86 | 3.67 ± 0.60 | 3.00 ± 0.90 | 6.83 ± 0.98 | 4.13 ± 2.25 |
| | track | 5.77 ± 1.01 | 2.75 ± 1.51 | 0.42 ± 0.22 | 5.05 ± 2.86 | 4.00 ± 0.90 | 2.27 ± 1.13 |
| Lichen + moss cover (%) | control | 1.84 ± 0.98 | 0.83 ± 0.56 | 0.83 ± 0.56 | 9.90 ± 4.54 | 7.92 ± 2.71 | 18.69 ± 3.59 |
| | track | 1.00 ± 0.41 | 0.79 ± 0.79 | 0.00 ± 0.00 | 3.85 ± 2.05 | 3.75 ± 1.52 | 4.62 ± 1.69 |
| Rock cover (%) | control | 34.4 ± 5.82 | 0.00 ± 0.00 | 1.65 ± 0.93 | 20.9 ± 6.84 | 19.2 ± 6.15 | 12.1 ± 3.73 |
| | track | 21.5 ± 3.34 | 0.00 ± 0.00 | 1.25 ± 0.65 | 35.4 ± 7.46 | 38.8 ± 9.30 | 17.2 ± 4.09 |
| Litter cover (%) | control | 3.97 ± 1.50 | 2.92 ± 0.96 | 2.55 ± 0.98 | 4.15 ± 2.42 | 6.47 ± 2.92 | 4.93 ± 2.21 |
| | track | 1.27 ± 0.75 | 9.56 ± 3.87 | 2.54 ± 0.98 | 0.45 ± 0.45 | 7.66 ± 2.53 | 5.95 ± 1.65 |

## Soil measures

| Coleogyne | | 20-year sites | | 40-year sites | | | |
|---|---|---|---|---|---|---|---|
| | | **CORA1** | **CORA2** | **CORA3** | **CORA4** | **CORA5** | **CORA6** |
| | | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** |
| Slake shallow | control | 2.22 ± 0.25 | 4.33 ± 0.40 | 2.67 ± 0.54 | 2.89 ± 0.81 | 5.06 ± 0.33 | 3.33 ± 0.52 |
| | track | 2.28 ± 0.31 | 1.44 ± 0.20 | 0.94 ± 0.33 | 1.44 ± 0.24 | 1.50 ± 0.17 | 1.44 ± 0.23 |
| Slake deep | control | 1.56 ± 0.34 | 1.00 ± 0.00 | 0.00 ± 0.00 | 1.33 ± 0.24 | 1.33 ± 0.17 | 1.00 ± 0.00 |
| | track | 0.78 ± 0.32 | 1.00 ± 0.00 | 0.56 ± 0.44 | 0.78 ± 0.15 | 1.44 ± 0.24 | 1.00 ± 0.00 |
| Species richness | control | 6.33 ± 1.20 | 4.00 ± 0.58 | 5.33 ± 0.88 | 3.00 ± 0.58 | 11.0 ± 1.00 | 11.0 ± 0.58 |
| | track | 5.00 ± 0.58 | 4.67 ± 0.88 | 3.00 ± 1.53 | 4.33 ± 1.20 | 5.00 ± 0.58 | 10.7 ± 2.03 |
| Interspace chlorophyll *a* (µg chl a/g soil) | control | 1.83 ± 0.08 | 4.48 ± 0.52 | 4.63 ± 1.31 | 1.76 ± 0.23 | 2.99 ± 0.45 | 3.10 ± 0.28 |
| | track | 1.72 ± 0.42 | 2.65 ± 0.70 | 2.11 ± 0.47 | 1.31 ± 0.24 | 2.27 ± 0.29 | 2.11 ± 0.50 |
| Undershrub chlorophyll *a* (µg chl a/g soil) | control | 2.06 ± 0.77 | 4.43 ± 0.65 | 2.70 ± 0.82 | 1.39 ± 0.28 | 2.23 ± 0.22 | 1.29 ± 0.12 |
| | track | 1.79 ± 0.32 | 2.52 ± 0.46 | 1.38 ± 0.12 | 1.26 ± 0.35 | 1.20 ± 0.36 | 1.21 ± 0.15 |
| Interspace length (m) | control | 1.16 ± 0.14 | 0.98 ± 0.17 | 0.64 ± 0.12 | 1.65 ± 0.31 | 0.78 ± 0.08 | 0.79 ± 0.08 |
| | track | 2.55 ± 0.70 | 2.62 ± 0.69 | 2.11 ± 0.67 | 3.92 ± 0.90 | 1.68 ± 0.44 | 1.24 ± 0.20 |
| Interspace cover (%) | control | 5.81 ± 0.69 | 4.90 ± 0.83 | 3.20 ± 0.58 | 8.25 ± 1.57 | 3.90 ± 0.39 | 3.97 ± 0.41 |
| | track | 12.8 ± 3.48 | 13.1 ± 3.46 | 10.6 ± 3.35 | 19.6 ± 4.52 | 8.40 ± 2.19 | 6.22 ± 0.99 |
| Coppice volume (m3) | control | 0.04 ± 0.01 | 0.08 ± 0.01 | 0.72 ± 0.25 | 0.07 ± 0.02 | 0.13 ± 0.03 | 0.12 ± 0.02 |
| | track | 0.01 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.08 ± 0.06 |
| Soil depth (cm) | control | 39.9 ± 3.44 | 41.7 ± 5.55 | 40.9 ± 4.44 | 11.07 ± 0.79 | 58.2 ± 2.24 | 46.3 ± 5.72 |
| | track | 48.6 ± 4.47 | 21.5 ± 1.51 | 19.20 ± 2.51 | 9.53 ± 0.80 | 34.7 ± 4.05 | 36.9 ± 4.60 |
| Soil resistance 0-5 cm (J/cm) | control | 0.88 ± 0.15 | 0.78 ± 0.14 | 0.25 ± 0.07 | 1.73 ± 0.42 | 0.47 ± 0.11 | 0.44 ± 0.09 |
| | track | 0.72 ± 0.09 | 0.65 ± 0.10 | 0.58 ± 0.10 | 1.34 ± 0.15 | 0.34 ± 0.10 | 0.46 ± 0.08 |
| Soil resistance 5-10 cm (J/cm) | control | 17.4 ± 1.10 | 2.25 ± 0.28 | 1.87 ± 0.24 | 13.8 ± 2.16 | 1.78 ± 0.29 | 5.26 ± 0.57 |
| | track | 20.4 ± 1.76 | 2.75 ± 0.17 | 6.26 ± 0.68 | 13.6 ± 2.11 | 1.65 ± 0.19 | 5.54 ± 0.53 |
| Soil resistance 10-15 cm (J/cm) | control | 46.8 ± 2.60 | 6.20 ± 0.59 | 5.41 ± 0.61 | 42.9 ± 6.29 | 4.57 ± 0.46 | 11.4 ± 1.06 |
| | track | 61.4 ± 5.63 | 8.02 ± 0.46 | 20.61 ± 1.89 | 50.0 ± 4.80 | 6.40 ± 0.47 | 19.3 ± 1.78 |
| Soil resistance 15-20 cm (J/cm) | control | 90.6 ± 5.18 | 11.5 ± 0.96 | 12.5 ± 1.92 | . ± . | 9.05 ± 0.56 | 19.1 ± 2.47 |
| | track | 122 ± 10.8 | 18.25 ± 1.56 | 40.5 ± 4.06 | 99.7 ± 1.05 | 17.2 ± 1.01 | 32.2 ± 2.98 |
| Magnetometer | control | 0.19 ± 0.01 | 0.09 ± 0.00 | 0.07 ± 0.00 | 0.05 ± 0.00 | 0.10 ± 0.00 | 0.12 ± 0.00 |
| | track | 0.17 ± 0.01 | 0.09 ± 0.00 | 0.07 ± 0.00 | 0.04 ± 0.00 | 0.07 ± 0.00 | 0.11 ± 0.00 |
| Shrub volume (m3) | control | 0.16 ± 0.04 | 0.16 ± 0.03 | 0.22 ± 0.03 | 0.05 ± 0.01 | 0.22 ± 0.04 | 0.38 ± 0.04 |
| | track | 0.09 ± 0.02 | 0.01 ± 0.00 | 0.03 ± 0.01 | 0.01 ± 0.00 | 0.08 ± 0.03 | 0.15 ± 0.07 |
| Shrub cover (%) | control | 23.1 ± 3.94 | 26.6 ± 3.29 | 30.6 ± 5.71 | 14.0 ± 2.86 | 30.3 ± 5.13 | 27.7 ± 9.95 |
| | track | 16.5 ± 6.36 | 4.93 ± 1.27 | 6.68 ± 1.88 | 2.37 ± 0.60 | 12.5 ± 3.40 | 5.00 ± 1.49 |
| Lichen + moss cover (%) | control | 2.88 ± 2.49 | 0.00 ± 0.00 | 0.38 ± 0.38 | 0.27 ± 0.27 | 10.0 ± 5.47 | 5.42 ± 3.45 |
| | track | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 1.21 ± 0.86 |
| Rock cover (%) | control | 6.77 ± 2.12 | 7.62 ± 4.33 | 1.47 ± 0.63 | 19.0 ± 3.14 | 0.00 ± 0.00 | 0.76 ± 0.76 |
| | track | 7.56 ± 2.00 | 0.79 ± 0.54 | 8.72 ± 4.07 | 15.7 ± 2.98 | 0.00 ± 0.00 | 3.04 ± 1.26 |
| Litter cover (%) | control | 5.42 ± 1.14 | 0.42 ± 0.42 | 0.00 ± 0.00 | 0.00 ± 0.00 | 4.58 ± 2.42 | 5.42 ± 1.89 |
| | track | 1.25 ± 0.65 | 0.00 ± 0.00 | 0.42 ± 0.42 | 0.81 ± 0.55 | 0.00 ± 0.00 | 1.23 ± 0.89 |

## Plant tissue chemistry

| **Artemisia** | | **20-year sites** | | | **40-year sites** | | |
|---|---|---|---|---|---|---|---|
| | | **ATSP1** | **ATSP2** | **ATSP3** | **ATSP4** | **ATSP5** | **ATSP6** |
| | | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** |
| N (%) | control | 1.37 ± 0.03 | 1.39 ± 0.03 | 1.62 ± 0.04 | . . | 1.34 ± 0.04 | 1.46 ± 0.02 |
| | track | 1.22 ± 0.04 | 1.43 ± 0.02 | 1.48 ± 0.05 | 1.66 ± 0.09 | 1.27 ± 0.03 | 1.34 ± 0.02 |
| Ca (%) | control | 0.76 ± 0.04 | 0.70 ± 0.07 | 0.75 ± 0.07 | . . | 0.66 ± 0.04 | 0.61 ± 0.02 |
| | track | 0.73 ± 0.03 | 0.50 ± 0.10 | 0.67 ± 0.10 | 0.60 ± 0.06 | 0.74 ± 0.08 | 0.64 ± 0.05 |
| Cu (ppm) | control | 9.21 ± 0.62 | 12.0 ± 0.72 | 10.3 ± 0.71 | . . | 9.59 ± 1.19 | 12.9 ± 0.94 |
| | track | 9.78 ± 1.07 | 9.44 ± 2.19 | 9.09 ± 1.13 | 9.97 ± 1.00 | 9.78 ± 0.18 | 13.2 ± 2.24 |
| Fe (ppm) | control | 310 ± 65.19 | 184 ± 8.65 | 241 ± 19.8 | . . | 186 ± 8.26 | 169 ± 7.94 |
| | track | 513 ± 219 | 228 ± 38.17 | 216 ± 12.8 | 192 ± 4.35 | 222 ± 39.7 | 172 ± 7.11 |
| K (%) | control | 1.21 ± 0.03 | 1.20 ± 0.02 | 1.42 ± 0.01 | . . | 1.17 ± 0.03 | 1.33 ± 0.03 |
| | track | 1.15 ± 0.08 | 1.15 ± 0.14 | 1.27 ± 0.12 | 1.46 ± 0.04 | 1.11 ± 0.07 | 1.35 ± 0.07 |
| Mg (%) | control | 0.17 ± 0.00 | 0.17 ± 0.01 | 0.19 ± 0.02 | . . | 0.15 ± 0.01 | 0.15 ± 0.01 |
| | track | 0.15 ± 0.01 | 0.13 ± 0.01 | 0.18 ± 0.02 | 0.15 ± 0.01 | 0.16 ± 0.01 | 0.14 ± 0.01 |
| Mn (ppm) | control | 91.3 ± 6.04 | 97.0 ± 9.85 | 87.5 ± 7.50 | . . | 61.8 ± 2.40 | 64.7 ± 5.55 |
| | track | 82.3 ± 9.42 | 81.5 ± 14.84 | 83.8 ± 10.6 | 70.4 ± 9.07 | 72.8 ± 9.01 | 55.6 ± 1.63 |
| P (%) | control | 0.18 ± 0.00 | 0.17 ± 0.01 | 0.29 ± 0.01 | . . | 0.16 ± 0.02 | 0.21 ± 0.01 |
| | track | 0.17 ± 0.01 | 0.14 ± 0.03 | 0.24 ± 0.01 | 0.22 ± 0.03 | 0.14 ± 0.03 | 0.19 ± 0.01 |
| S (%) | control | 0.20 ± 0.01 | 0.13 ± 0.01 | 0.25 ± 0.01 | . . | 0.12 ± 0.00 | 0.13 ± 0.01 |
| | track | 0.17 ± 0.01 | 0.12 ± 0.01 | 0.20 ± 0.02 | 0.15 ± 0.01 | 0.12 ± 0.01 | 0.13 ± 0.00 |
| Zn (ppm) | control | 27.4 ± 1.44 | 19.2 ± 0.23 | 29.1 ± 1.28 | . . | 23.0 ± 2.36 | 29.0 ± 3.09 |
| | track | 20.6 ± 1.72 | 16.9 ± 3.30 | 26.2 ± 0.71 | 26.0 ± 2.99 | 19.1 ± 0.55 | 26.5 ± 1.04 |
| Na (%) | control | . . | . . | . . | . . | . . | . . |
| | track | . . | . . | . . | . . | . . | . . |
| δ13C | control | -26.4 ± 0.10 | -26.7 ± 0.22 | -26.0 ± 0.05 | . . | -26.5 ± 0.27 | -26.6 ± 0.11 |
| | track | -26.5 ± 0.25 | -27.3 ± 0.37 | -26.4 ± 0.17 | -26.0 ± 0.39 | -26.8 ± 0.15 | -27.1 ± 0.35 |
| δ15N | control | 0.85 ± 0.15 | 1.87 ± 0.14 | 2.22 ± 0.28 | . . | 1.95 ± 0.16 | 1.98 ± 0.15 |
| | track | 0.59 ± 0.17 | 1.47 ± 0.30 | 2.67 ± 0.39 | 1.91 ± 0.22 | 1.98 ± 0.25 | 2.47 ± 0.22 |
| C (%) | control | 49.5 ± 0.17 | 49.9 ± 0.08 | 50.7 ± 0.23 | . . | 49.6 ± 0.11 | 50.0 ± 0.24 |
| | track | 49.2 ± 0.36 | 49.7 ± 0.45 | 50.2 ± 0.15 | 50.4 ± 0.27 | 49.5 ± 0.26 | 49.4 ± 0.18 |
| N (%) | control | 1.26 ± 0.05 | 1.17 ± 0.03 | 1.39 ± 0.00 | . . | 1.19 ± 0.04 | 1.29 ± 0.01 |
| | track | 1.11 ± 0.06 | 1.17 ± 0.04 | 1.26 ± 0.04 | 1.46 ± 0.10 | 1.12 ± 0.01 | 1.23 ± 0.02 |
| C/N | control | 39.5 ± 1.58 | 42.8 ± 1.25 | 36.4 ± 0.11 | . . | 41.8 ± 1.33 | 38.9 ± 0.47 |
| | track | 44.7 ± 2.45 | 42.7 ± 1.12 | 39.9 ± 1.23 | 34.8 ± 2.23 | 44.2 ± 0.15 | 40.2 ± 0.49 |

## Plant tissue chemistry

| Atriplex | | 20-year sites | | | 40-year sites | | |
|---|---|---|---|---|---|---|---|
| | | ARTR1 | ARTR2 | ARTR3 | ARTR4 | ARTR5 | ARTR6 |
| | | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE |
| N (%) | control | 1.77 ± 0.12 | 1.71 ± 0.10 | 1.59 ± 0.21 | 1.93 ± 0.23 | 1.78 ± 0.03 | 1.66 ± 0.02 |
| | track | 1.79 ± 0.01 | 2.02 ± 0.05 | 1.51 ± 0.09 | 1.84 ± 0.19 | 1.87 ± 0.18 | 1.91 . |
| Ca (%) | control | 2.83 ± 0.73 | 3.71 ± 0.38 | 3.01 ± 0.14 | 2.61 ± 0.18 | 3.34 ± 0.24 | 2.54 ± 0.13 |
| | track | 1.79 ± 0.07 | 3.58 ± 0.13 | 3.17 ± 0.27 | 2.90 ± 0.36 | 3.33 ± 0.37 | 2.38 . |
| Cu (ppm) | control | 3.17 ± 1.20 | 7.12 ± 0.18 | 4.15 ± 2.07 | 1.83 ± 0.05 | 2.03 ± 0.19 | 2.07 ± 0.14 |
| | track | 2.81 ± 0.67 | 7.47 ± 0.28 | 7.78 ± 0.36 | 2.26 ± 0.14 | 2.64 ± 0.95 | 3.20 . |
| Fe (ppm) | control | 486 ± 113 | 491 ± 181 | 654 ± 214 | 219 ± 75.1 | 390 ± 233 | 306 ± 131 |
| | track | 715 ± 68.0 | 437 ± 79.5 | 962 ± 64.6 | 358 ± 26.2 | 145 ± 13.0 | 913 . |
| K (%) | control | 0.97 ± 0.20 | 0.85 ± 0.01 | 1.25 ± 0.30 | 1.91 ± 0.40 | 1.44 ± 0.17 | 1.01 ± 0.15 |
| | track | 1.39 ± 0.39 | 0.81 ± 0.16 | 1.14 ± 0.06 | 2.33 ± 0.49 | 1.53 ± 0.21 | 1.03 . |
| Mg (%) | control | 0.88 ± 0.06 | 1.10 ± 0.04 | 1.02 ± 0.13 | 0.76 ± 0.04 | 0.85 ± 0.02 | 0.87 ± 0.03 |
| | track | 0.83 ± 0.06 | 1.02 ± 0.06 | 1.03 ± 0.04 | 0.82 ± 0.07 | 0.86 ± 0.07 | 0.67 . |
| Mn (ppm) | control | 55.3 ± 7.31 | 76.0 ± 3.35 | 81.3 ± 12.0 | 84.1 ± 9.43 | 97.9 ± 2.06 | 89.1 ± 11.3 |
| | track | 63.1 ± 4.68 | 71.2 ± 5.44 | 82.6 ± 6.57 | 68.5 ± 3.91 | 93.9 ± 23.11 | 68.3 . |
| P (%) | control | 0.09 ± 0.01 | 0.06 ± 0.01 | 0.07 ± 0.00 | 0.07 ± 0.01 | 0.08 ± 0.01 | 0.06 ± 0.01 |
| | track | 0.11 ± 0.02 | 0.06 ± 0.00 | 0.07 ± 0.00 | 0.07 ± 0.01 | 0.10 ± 0.02 | 0.07 . |
| S (%) | control | 0.85 ± 0.05 | 0.70 ± 0.09 | 0.58 ± 0.10 | 0.41 ± 0.08 | 0.56 ± 0.21 | 0.95 ± 0.11 |
| | track | 1.07 ± 0.24 | 0.80 ± 0.16 | 0.61 ± 0.07 | 0.41 ± 0.03 | 0.32 ± 0.08 | 0.72 . |
| Zn (ppm) | control | 10.8 ± 2.68 | 23.1 ± 2.80 | 25.5 ± 4.25 | 12.6 ± 1.93 | 9.00 ± 3.12 | 10.4 ± 1.76 |
| | track | 20.8 ± 3.18 | 17.9 ± 0.86 | 23.7 ± 3.09 | 19.6 ± 3.70 | 9.82 ± 0.35 | 13.1 . |
| Na (%) | control | 5.08 ± 0.73 | 4.70 ± 0.06 | 5.13 ± 0.13 | 4.91 ± 0.34 | 5.07 ± 0.46 | 5.64 ± 0.13 |
| | track | 5.45 ± 0.02 | 5.14 ± 0.18 | 5.10 ± 0.28 | 5.67 ± 0.33 | 4.27 ± 0.34 | 5.26 . |
| δ13C | control | -14.9 ± 0.13 | -14.3 ± 0.18 | -14.0 ± 0.11 | -14.3 ± 0.21 | -14.2 ± 0.15 | -14.3 ± 0.14 |
| | track | -15.0 ± 0.31 | -14.5 ± 0.28 | -14.0 ± 0.04 | -14.4 ± 0.34 | -14.7 ± 0.23 | -14.3 ± 0.23 |
| δ15N | control | 1.38 ± 0.51 | 3.50 ± 0.46 | 1.61 ± 0.40 | 5.06 ± 0.29 | 6.06 ± 0.40 | 6.74 ± 0.26 |
| | track | 1.20 ± 0.64 | 3.79 ± 0.51 | 1.51 ± 0.51 | 5.10 ± 0.24 | 6.41 ± 0.78 | 7.53 ± 1.74 |
| C (%) | control | 30.8 ± 0.36 | 30.3 ± 0.06 | 30.2 ± 0.05 | 30.7 ± 0.49 | 31.4 ± 1.13 | 30.4 ± 0.26 |
| | track | 30.9 ± 1.41 | 31.2 ± 0.74 | 29.5 ± 0.41 | 29.7 ± 0.88 | 31.5 ± 0.76 | 29.3 ± 0.27 |
| N (%) | control | 1.79 ± 0.07 | 1.75 ± 0.06 | 1.35 ± 0.04 | 1.71 ± 0.12 | 1.62 ± 0.18 | 1.63 ± 0.03 |
| | track | 1.83 ± 0.15 | 1.80 ± 0.24 | 1.28 ± 0.10 | 1.72 ± 0.26 | 1.99 ± 0.07 | 1.57 ± 0.08 |
| C/N | control | 17.3 ± 0.51 | 17.4 ± 0.56 | 22.4 ± 0.66 | 18.1 ± 1.05 | 19.7 ± 1.61 | 18.7 ± 0.60 |
| | track | 17.1 ± 0.73 | 17.8 ± 1.83 | 23.3 ± 1.98 | 18.1 ± 2.72 | 15.8 ± 0.26 | 18.7 ± 0.67 |

## Plant tissue chemistry

| Coleogyne | | 20-year sites | | 40-year sites | | | |
|---|---|---|---|---|---|---|---|
| | | CORA1 | CORA2 | CORA3 | CORA4 | CORA5 | CORA6 |
| | | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** |
| N (%) | control | 1.34 ± 0.04 | 1.26 ± 0.03 | 1.26 ± 0.04 | 1.01 ± 0.04 | 1.23 ± 0.03 | 1.15 ± 0.01 |
| | track | 1.41 ± 0.05 | 1.24 ± 0.03 | 1.56 ± 0.07 | 1.02 ± 0.01 | 0.91 ± 0.05 | 1.13 . |
| Ca (%) | control | 3.26 ± 0.24 | 2.86 ± 0.05 | 3.00 ± 0.01 | 3.26 ± 0.11 | 3.03 ± 0.32 | 3.07 ± 0.13 |
| | track | 3.53 ± 0.10 | 2.76 ± 0.10 | 2.82 ± 0.04 | 3.06 ± 0.15 | 3.51 ± 0.18 | 2.76 . |
| Cu (ppm) | control | 6.15 ± 1.30 | 7.36 ± 1.50 | 5.01 ± 0.90 | 5.77 ± 0.98 | 1.78 ± 0.97 | 8.61 ± 2.21 |
| | track | 8.61 ± 2.44 | 9.43 ± 0.18 | 5.62 ± 0.35 | 8.83 ± 1.80 | 3.80 ± 0.43 | 11.1 . |
| Fe (ppm) | control | 257 ± 22.9 | 340 ± 65.8 | 250 ± 22.1 | 304 ± 22.7 | 233 ± 19.9 | 175 ± 9.34 |
| | track | 265 ± 1.98 | 312 ± 2.79 | 246 ± 22.4 | 289 ± 17.1 | 281 ± 28.7 | 253 . |
| K (%) | control | 0.69 ± 0.03 | 0.64 ± 0.01 | 0.55 ± 0.01 | 0.73 ± 0.07 | 0.54 ± 0.07 | 0.65 ± 0.03 |
| | track | 0.89 ± 0.04 | 0.65 ± 0.00 | 0.58 ± 0.02 | 0.71 ± 0.02 | 0.54 ± 0.02 | 0.68 . |
| Mg (%) | control | 0.27 ± 0.01 | 0.38 ± 0.04 | 0.30 ± 0.01 | 0.36 ± 0.07 | 0.25 ± 0.02 | 0.30 ± 0.00 |
| | track | 0.29 ± 0.04 | 0.25 ± 0.01 | 0.29 ± 0.01 | 0.32 ± 0.10 | 0.26 ± 0.01 | 0.28 . |
| Mn (ppm) | control | 56.0 ± 2.69 | 54.8 ± 1.36 | 49.9 ± 2.29 | 60.7 ± 6.07 | 43.3 ± 3.42 | 42.7 ± 6.06 |
| | track | 62.7 ± 4.94 | 46.6 ± 1.82 | 48.7 ± 1.88 | 69.3 ± 5.71 | 48.4 ± 2.28 | 29.3 . |
| P (%) | control | 0.09 ± 0.00 | 0.09 ± 0.00 | 0.09 ± 0.00 | 0.08 ± 0.00 | 0.09 ± 0.01 | 0.08 ± 0.00 |
| | track | 0.09 ± 0.01 | 0.08 ± 0.00 | 0.07 ± 0.00 | 0.08 ± 0.00 | 0.08 ± 0.00 | 0.08 . |
| S (%) | control | 0.11 ± 0.01 | 0.11 ± 0.01 | 0.10 ± 0.00 | 0.10 ± 0.01 | 0.10 ± 0.01 | 0.09 ± 0.00 |
| | track | 0.12 ± 0.01 | 0.11 ± 0.01 | 0.09 ± 0.00 | 0.10 ± 0.00 | 0.09 ± 0.00 | 0.08 . |
| Zn (ppm) | control | 22.9 ± 1.22 | 25.7 ± 0.33 | 32.7 ± 0.64 | 26.8 ± 2.15 | 27.0 ± 0.33 | 21.7 ± 0.81 |
| | track | 23.6 ± 1.78 | 24.8 ± 0.85 | 32.4 ± 1.31 | 30.1 ± 1.44 | 27.4 ± 1.05 | 30.8 . |
| Na (%) | control | . . | . . | . . | . . | . . | . . |
| | track | . . | . . | . . | . . | . . | . . |
| δ13C | control | -24.9 ± 0.08 | -24.5 ± 0.17 | -24.6 ± 0.23 | -24.7 ± 0.29 | -24.5 ± 0.04 | -24.5 ± 0.26 |
| | track | -25.3 ± 0.15 | -25.1 ± 0.14 | -25.3 ± 0.10 | -25.3 ± 0.12 | -25.8 ± 0.13 | -24.9 . |
| δ15N | control | -1.32 ± 0.14 | 0.20 ± 0.10 | -0.8 ± 0.04 | -3.40 ± 0.15 | -0.77 ± 0.18 | 0.92 ± 0.31 |
| | track | -1.31 ± 0.05 | 0.03 ± 0.20 | -0.22 ± 0.23 | -3.57 ± 0.16 | -0.22 ± 0.23 | 0.43 . |
| C (%) | control | 45.5 ± 0.06 | 45.7 ± 0.13 | 46.4 ± 0.11 | 46.3 ± 0.21 | 46.4 ± 0.11 | 46.4 ± 0.19 |
| | track | 45.4 ± 0.17 | 45.6 ± 0.22 | 46.5 ± 0.27 | 46.0 ± 0.58 | 46.8 ± 0.19 | 46.0 . |
| N (%) | control | 1.28 ± 0.05 | 1.19 ± 0.05 | 1.21 ± 0.03 | 1.03 ± 0.03 | 1.24 ± 0.02 | 1.12 ± 0.03 |
| | track | 1.40 ± 0.06 | 1.22 ± 0.03 | 1.10 ± 0.02 | 0.99 ± 0.01 | 0.95 ± 0.08 | 1.08 . |
| C/N | control | 35.6 ± 1.25 | 38.4 ± 1.67 | 38.5 ± 0.90 | 45.0 ± 1.04 | 37.4 ± 0.50 | 41.4 ± 0.97 |
| | track | 32.6 ± 1.69 | 37.4 ± 0.74 | 42.4 ± 0.88 | 46.2 ± 0.25 | 49.7 ± 3.94 | 42.4 . |

## Soil chemistry, 0-0.5 cm

| Artemisia | | 20-year sites | | | 40-year sites | | |
|---|---|---|---|---|---|---|---|
| | | ATSP1 | ATSP2 | ATSP3 | ATSP4 | ATSP5 | ATSP6 |
| | | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE |
| P (ppm) | control | 9.21 ± 0.64 | 11.5 ± 0.40 | 8.88 ± 0.66 | 9.75 ± 1.33 | 9.11 ± 0.52 | 10.9 ± 1.61 |
| | track | 8.79 ± 0.70 | 10.1 ± 0.15 | 7.72 ± 0.22 | 9.16 ± 1.82 | 8.67 ± 0.91 | 10.6 ± 0.63 |
| $K_{av}$ (ppm) | control | 131 ± 5.54 | 132 ± 5.10 | 113 ± 6.99 | 91.7 ± 30.9 | 174 ± 23.1 | 115 ± 15.8 |
| | track | 116 ± 15.9 | 106 ± 3.20 | 88.5 ± 1.07 | 88.5 ± 27.8 | 135 ± 27.8 | 128 ± 11.5 |
| OM (%) | control | 1.83 ± 0.41 | 2.94 ± 0.37 | 2.56 ± 0.46 | 2.48 ± 0.33 | 1.20 ± 0.25 | 0.84 ± 0.19 |
| | track | 2.25 ± 0.46 | 1.78 ± 0.15 | 1.45 ± 0.12 | 1.44 ± 0.16 | 1.38 ± 0.45 | 0.92 ± 0.08 |
| pH | control | 7.00 ± 0.06 | 6.50 ± 0.07 | 7.24 ± 0.27 | 6.79 ± 0.17 | 7.19 ± 0.22 | 7.11 ± 0.06 |
| | track | 7.00 ± 0.10 | 6.51 ± 0.09 | 6.92 ± 0.07 | 6.91 ± 0.16 | 7.53 ± 0.19 | 7.18 ± 0.10 |
| CEC (meq/100 g) | control | 4.54 ± 1.14 | 5.21 ± 0.23 | 4.51 ± 0.51 | 3.68 ± 1.18 | 3.77 ± 0.96 | 4.25 ± 0.60 |
| | track | 3.93 ± 0.46 | 4.48 ± 0.24 | 4.12 ± 0.50 | 3.36 ± 1.17 | 3.87 ± 0.66 | 5.64 ± 0.42 |
| Zn (ppm) | control | 0.46 ± 0.09 | 0.70 ± 0.03 | 0.47 ± 0.01 | 0.62 ± 0.11 | 0.62 ± 0.10 | 0.73 ± 0.05 |
| | track | 0.44 ± 0.04 | 0.64 ± 0.03 | 0.42 ± 0.00 | 0.49 ± 0.08 | 0.61 ± 0.14 | 0.94 ± 0.18 |
| Fe (ppm) | control | 5.24 ± 0.71 | 8.32 ± 0.39 | 5.00 ± 0.21 | 5.63 ± 0.80 | 6.01 ± 1.38 | 4.47 ± 0.41 |
| | track | 5.17 ± 0.70 | 9.75 ± 1.75 | 5.16 ± 0.17 | 5.29 ± 0.83 | 5.67 ± 1.32 | 4.72 ± 0.35 |
| Mn (ppm) | control | 7.52 ± 0.59 | 13.1 ± 1.15 | 7.10 ± 0.38 | 8.58 ± 1.15 | 12.9 ± 1.49 | 8.72 ± 0.83 |
| | track | 8.05 ± 0.44 | 9.57 ± 0.28 | 5.29 ± 0.53 | 6.80 ± 1.00 | 11.8 ± 3.66 | 10.4 ± 1.59 |
| Cu (ppm) | control | 0.37 ± 0.06 | 0.63 ± 0.03 | 0.44 ± 0.02 | 0.38 ± 0.03 | 0.49 ± 0.06 | 0.58 ± 0.07 |
| | track | 0.40 ± 0.05 | 0.59 ± 0.03 | 0.46 ± 0.02 | 0.35 ± 0.04 | 0.50 ± 0.05 | 0.64 ± 0.10 |
| $Ca_{ex}$ (ppm) | control | 996 ± 161 | 940 ± 30.59 | 1192 ± 234 | 1399 ± 720 | 1285 ± 383 | 837 ± 69.9 |
| | track | 1319 ± 318 | 783 ± 25.31 | 1042 ± 308 | 1311 ± 745 | 1663 ± 443 | 1035 ± 113 |
| $Mg_{ex}$ (ppm) | control | 129 ± 18.9 | 148 ± 3.25 | 142 ± 17.5 | 121 ± 24.4 | 131 ± 16.6 | 153 ± 18.3 |
| | track | 115 ± 14.5 | 147 ± 4.83 | 123 ± 6.33 | 113 ± 21.4 | 123 ± 22.9 | 143 ± 10.1 |
| $K_{ex}$ (ppm) | control | 161 ± 13.3 | 161 ± 8.62 | 136 ± 10.1 | 136 ± 35.1 | 174 ± 29.5 | 132 ± 21.2 |
| | track | 144 ± 15.7 | 133 ± 8.18 | 104 ± 13.0 | 117 ± 35.2 | 154 ± 25.7 | 143 ± 11.3 |
| $Na_{ex}$ (ppm) | control | 41.5 ± 1.99 | 40.8 ± 4.54 | 24.4 ± 4.11 | 42.6 ± 3.47 | 17.3 ± 0.93 | 15.9 ± 0.13 |
| | track | 39.7 ± 1.62 | 43.1 ± 6.40 | 25.4 ± 2.12 | 42.5 ± 17.2 | 15.8 ± 0.31 | 17.1 ± 1.33 |
| Total N (ppm) | control | 55.8 ± 21.2 | 1190 ± 1030 | 871 ± 775 | 1353 ± 1175 | 488 ± 114 | 397 ± 11.8 |
| | track | 90.5 ± 33.8 | 376 ± 224 | 72.7 ± 10.3 | 78.9 ± 52.4 | 416 ± 110 | 488 ± 22.6 |
| ANP (%) | control | 0.99 ± 0.22 | 0.99 ± 0.43 | 0.75 ± 0.07 | 1.37 ± 0.78 | 1.30 ± 0.55 | 0.98 ± 0.07 |
| | track | 1.42 ± 0.32 | 0.68 ± 0.07 | 1.01 ± 0.17 | 1.77 ± 1.30 | 1.99 ± 0.53 | 1.03 ± 0.32 |
| Very Coarse | control | 0.04 ± 0.02 | 0.07 ± 0.03 | 0.03 ± 0.03 | 0.14 ± 0.11 | 0.47 ± 0.10 | 0.09 ± 0.01 |
| | track | 0.07 ± 0.03 | 0.06 ± 0.02 | 0.04 ± 0.01 | 0.15 ± 0.14 | 0.49 ± 0.23 | 0.17 ± 0.03 |
| Coarse | control | 0.09 ± 0.01 | 0.14 ± 0.06 | 0.08 ± 0.08 | 0.17 ± 0.09 | 0.39 ± 0.09 | 0.22 ± 0.02 |
| | track | 0.08 ± 0.01 | 0.06 ± 0.02 | 0.09 ± 0.01 | 0.16 ± 0.10 | 0.43 ± 0.22 | 0.17 ± 0.02 |
| Medium | control | 0.91 ± 0.17 | 1.23 ± 0.10 | 0.38 ± 0.38 | 3.48 ± 0.30 | 1.21 ± 0.12 | 0.63 ± 0.13 |
| | track | 1.11 ± 0.28 | 1.11 ± 0.09 | 0.76 ± 0.32 | 5.55 ± 1.09 | 1.77 ± 0.59 | 0.59 ± 0.07 |
| Fine | control | 37.3 ± 6.10 | 29.3 ± 0.81 | 7.53 ± 7.53 | 37.4 ± 7.45 | 36.7 ± 10.7 | 33.5 ± 3.96 |
| | track | 37.3 ± 3.64 | 28.3 ± 1.88 | 30.0 ± 1.88 | 42.0 ± 9.57 | 37.7 ± 10.5 | 31.7 ± 2.04 |
| Very Fine | control | 38.1 ± 3.23 | 32.9 ± 1.19 | 12.5 ± 12.5 | 31.3 ± 1.53 | 38.6 ± 6.80 | 34.1 ± 2.02 |
| | track | 38.4 ± 1.97 | 32.6 ± 0.18 | 35.0 ± 3.95 | 27.9 ± 3.40 | 32.8 ± 5.12 | 32.5 ± 0.92 |
| Sand (%) | control | 71.5 ± 2.03 | 64.5 ± 1.00 | 62.4 ± 2.00 | 72.4 ± 3.77 | 67.3 ± 7.09 | 65.3 ± 2.56 |
| | track | 75.2 ± 2.08 | 64.3 ± 0.68 | 64.8 ± 0.67 | 72.8 ± 5.61 | 68.4 ± 4.98 | 66.0 ± 2.31 |
| Clay (%) | control | 9.27 ± 0.41 | 9.48 ± 0.00 | 9.53 ± 0.88 | 8.23 ± 0.88 | 12.5 ± 0.67 | 13.4 ± 1.07 |
| | track | 9.51 ± 0.67 | 9.81 ± 0.33 | 10.5 ± 0.33 | 9.44 ± 0.63 | 12.3 ± 0.24 | 13.7 ± 0.12 |
| Silt (%) | control | 19.2 ± 1.63 | 26.0 ± 1.00 | 28.0 ± 1.45 | 19.3 ± 3.05 | 20.2 ± 6.58 | 21.3 ± 2.13 |
| | track | 15.3 ± 1.45 | 25.9 ± 0.73 | 24.7 ± 0.33 | 17.8 ± 5.20 | 19.3 ± 5.21 | 20.3 ± 2.21 |
| N/P | control | 5.78 ± 2.02 | 107 ± 92.8 | 112 ± 102 | 185 ± 168 | 53.5 ± 12.5 | 37.9 ± 5.78 |
| | track | 11.1 ± 5.05 | 36.94 ± 21.7 | 9.39 ± 1.13 | 7.12 ± 3.82 | 50.7 ± 17.3 | 46.5 ± 2.61 |
| $NO_3 = NO_2$ (ppm) | track | 2524 ± 380 | 1764 ± 143 | 1879 ± 120 | 1632 ± 185 | 1724 ± 725 | 872 ± 76.2 |
| | control | 0.15 ± 0.02 | 0.14 ± 0.02 | 0.12 ± 0.03 | 0.14 ± 0.04 | 0.11 ± 0.02 | 0.12 ± 0.02 |
| $NH_4$ (ppm) | track | 0.19 ± 0.01 | 0.15 ± 0.02 | 0.11 ± 0.03 | 0.14 ± 0.04 | 0.06 ± 0.01 | 0.12 ± 0.02 |
| | control | 0.49 ± 0.12 | 0.39 ± 0.05 | 0.47 ± 0.01 | 0.52 ± 0.06 | 0.39 ± 0.05 | 0.44 ± 0.02 |
| | track | 0.56 ± 0.12 | 0.46 ± 0.03 | 0.39 ± 0.06 | 0.53 ± 0.10 | 0.35 ± 0.07 | 0.46 ± 0.06 |

## Soil chemistry, 0-0.5 cm

| Atriplex | | 20-year sites | | | 40-year sites | | |
|---|---|---|---|---|---|---|---|
| | | ARTR1 | ARTR2 | ARTR3 | ARTR4 | ARTR5 | ARTR6 |
| | | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE |
| P (ppm) | control | 15.3 ± 0.80 | 14.8 ± 3.39 | 8.22 ± 0.41 | 20.8 ± 1.20 | 16.4 ± 1.93 | 11.2 ± 1.20 |
| | track | 14.0 ± 1.12 | 14.1 ± 2.37 | 9.44 ± 1.56 | 15.5 ± 0.17 | 13.3 ± 0.14 | 11.1 ± 13.9 |
| $K_{av}$ (ppm) | control | 219 ± 13.4 | 325.33 ± 55.2 | 203 ± 10.7 | 115 ± 15.1 | 147 ± 25.4 | 122.67 ± 13.95 |
| | track | 193 ± 4.65 | 349 ± 52.4 | 160 ± 0.00 | 146 ± 12.4 | 118 ± 22.4 | 112.00 ± 0.20 |
| OM (%) | control | 2.09 ± 0.03 | 3.33 ± 0.39 | 1.74 ± 0.06 | 1.75 ± 0.32 | 1.91 ± 0.21 | 2.39 ± 0.39 |
| | track | 2.08 ± 0.02 | 3.26 ± 0.32 | 1.80 ± 0.19 | 1.19 ± 0.16 | 1.55 ± 0.14 | 2.32 ± 0.10 |
| pH | control | 7.16 ± 0.09 | 7.52 ± 0.14 | 7.44 ± 0.10 | 7.78 ± 0.10 | 7.82 ± 0.24 | 8.06 ± 0.04 |
| | track | 7.05 ± 0.06 | 7.38 ± 0.25 | 7.27 ± 0.07 | 7.81 ± 0.05 | 7.55 ± 0.11 | 7.92 ± 0.09 |
| CEC (meq/100 g) | control | 11.6 ± 0.80 | 19.0 ± 13.0 | 8.86 ± 0.98 | 4.74 ± 0.07 | 5.81 ± 1.05 | 4.84 ± 2.04 |
| | track | 12.0 ± 2.10 | 7.71 ± 0.76 | 17.9 ± 9.97 | 4.92 ± 0.07 | 6.07 ± 0.07 | 6.68 ± 0.08 |
| Zn (ppm) | control | 0.67 ± 0.01 | 0.58 ± 0.03 | 0.45 ± 0.02 | 0.88 ± 0.14 | 0.43 ± 0.01 | 0.65 ± 0.11 |
| | track | 0.90 ± 0.21 | 0.52 ± 0.07 | 0.42 ± 0.03 | 0.49 ± 0.20 | 0.38 ± 0.02 | 0.66 ± 0.68 |
| Fe (ppm) | control | 2.29 ± 0.16 | 2.68 ± 0.06 | 1.38 ± 0.09 | 13.6 ± 5.13 | 1.67 ± 0.12 | 5.27 ± 1.25 |
| | track | 2.17 ± 0.28 | 2.66 ± 0.23 | 1.41 ± 0.07 | 8.96 ± 6.59 | 1.49 ± 0.39 | 3.93 ± 0.25 |
| Mn (ppm) | control | 2.88 ± 0.47 | 6.21 ± 0.44 | 2.23 ± 0.19 | 28.1 ± 11.2 | 2.91 ± 0.22 | 4.59 ± 0.11 |
| | track | 3.35 ± 0.58 | 6.53 ± 0.89 | 2.43 ± 0.14 | 15.6 ± 11.4 | 3.03 ± 1.16 | 3.71 ± 0.04 |
| Cu (ppm) | control | 0.63 ± 0.02 | 0.73 ± 0.12 | 0.61 ± 0.10 | 1.00 ± 0.23 | 0.47 ± 0.11 | 0.46 ± 0.19 |
| | track | 0.67 ± 0.05 | 0.75 ± 0.08 | 0.78 ± 0.11 | 0.80 ± 0.27 | 0.52 ± 0.09 | 0.64 ± 76.8 |
| $Ca_{ex}$ (ppm) | control | 17183 ± 10900 | 3120 ± 349 | 3361 ± 362 | 2647 ± 248 | 2907 ± 398 | 1776 ± 48.9 |
| | track | 8229 ± 3553 | 2892 ± 28.9 | 4610 ± 232 | 2321 ± 51.8 | 2709 ± 93.0 | 1829 ± 20.9 |
| $Mg_{ex}$ (ppm) | control | 121 ± 39.2 | 463 ± 104 | 135 ± 3.82 | 185 ± 26.4 | 186 ± 15.6 | 170 ± 7.07 |
| | track | 117 ± 37.0 | 342 ± 37.3 | 95.1 ± 13.6 | 152 ± 11.4 | 215 ± 13.5 | 168 ± 11.7 |
| $K_{ex}$ (ppm) | control | 219 ± 27.2 | 377 ± 33.0 | 177 ± 6.27 | 178 ± 12.6 | 217 ± 30.4 | 195 ± 18.7 |
| | track | 217 ± 4.36 | 403 ± 68.9 | 153 ± 7.73 | 160 ± 18.8 | 188 ± 21.0 | 178 ± 61.5 |
| $Na_{ex}$ (ppm) | control | 149 ± 17.0 | 471 ± 73.9 | 155 ± 24.4 | 91.0 ± 16.2 | 179 ± 17.5 | 226 ± 48.0 |
| | track | 134 ± 29.6 | 465 ± 69.7 | 116 ± 36.2 | 98.3 ± 15.0 | 177 ± 3.46 | 258 ± 40.4 |
| Total N (ppm) | control | 82.0 ± 12.2 | 439 ± 61.4 | 70.7 ± 32.8 | 69.7 ± 20.4 | 491 ± 70.6 | 537 ± 74.5 |
| | track | 56.4 ± 14.7 | 423 ± 132 | 36.4 ± 7.90 | 206 ± 102 | 467 ± 42.4 | 552 ± 0.51 |
| ANP (%) | control | 14.5 ± 3.26 | 18.1 ± 0.14 | 16.8 ± 0.88 | 13.8 ± 0.47 | 7.04 ± 0.05 | 5.98 ± 0.56 |
| | track | 14.8 ± 3.34 | 18.2 ± 0.30 | 15.9 ± 0.75 | 12.7 ± 1.66 | 7.13 ± 0.12 | 6.00 ± 0.56 |
| Very Coarse | control | 1.22 ± 0.36 | 0.35 ± 0.08 | 0.43 ± 0.17 | 1.24 ± 0.16 | 2.45 ± 1.03 | 1.52 ± 0.22 |
| | track | 0.92 ± 0.28 | 0.23 ± 0.07 | 0.45 ± 0.12 | 2.10 ± 0.39 | 1.86 ± 0.03 | 1.46 ± 0.37 |
| Coarse | control | 1.80 ± 0.42 | 0.50 ± 0.10 | 0.67 ± 0.13 | 1.69 ± 0.21 | 2.23 ± 0.84 | 1.63 ± 0.24 |
| | track | 1.43 ± 0.31 | 0.40 ± 0.07 | 0.65 ± 0.14 | 2.68 ± 0.50 | 1.83 ± 0.06 | 2.00 ± 0.93 |
| Medium | control | 2.27 ± 0.24 | 0.64 ± 0.27 | 1.30 ± 0.34 | 4.81 ± 0.46 | 3.81 ± 1.46 | 5.40 ± 0.84 |
| | track | 1.80 ± 0.22 | 0.80 ± 0.04 | 0.99 ± 0.15 | 5.81 ± 0.71 | 3.60 ± 0.38 | 5.21 ± 2.29 |
| Fine | control | 12.3 ± 1.71 | 5.93 ± 2.69 | 13.0 ± 2.75 | 13.0 ± 0.82 | 13.1 ± 3.34 | 20.4 ± 3.15 |
| | track | 11.4 ± 2.38 | 6.45 ± 0.62 | 11.7 ± 1.33 | 16.9 ± 0.62 | 13.0 ± 2.49 | 17.4 ± 3.99 |
| Very Fine | control | 13.1 ± 2.13 | 13.9 ± 6.50 | 28.4 ± 9.22 | 23.2 ± 2.37 | 22.0 ± 3.58 | 23.7 ± 2.80 |
| | track | 14.2 ± 1.21 | 15.4 ± 1.46 | 28.2 ± 3.16 | 19.2 ± 1.48 | 20.9 ± 0.29 | 11.5 ± 2.32 |
| Sand (%) | control | 45.7 ± 1.73 | 49.7 ± 8.10 | 50.0 ± 3.06 | 48.3 ± 0.29 | 50.4 ± 3.61 | 56.5 ± 1.84 |
| | track | 44.6 ± 2.19 | 37.6 ± 2.00 | 48.7 ± 2.91 | 54.6 ± 1.74 | 46.4 ± 3.00 | 55.8 ± 0.67 |
| Clay (%) | control | 24.1 ± 0.50 | 14.2 ± 0.67 | 22.6 ± 2.31 | 11.1 ± 0.62 | 16.8 ± 2.96 | 10.5 ± 0.67 |
| | track | 23.6 ± 0.67 | 19.6 ± 1.05 | 25.2 ± 1.76 | 11.8 ± 1.08 | 22.0 ± 3.50 | 12.5 ± 2.21 |
| Silt (%) | control | 28.5 ± 0.32 | 36.2 ± 8.66 | 27.4 ± 1.15 | 40.7 ± 0.39 | 32.8 ± 0.67 | 33.0 ± 2.33 |
| | track | 31.8 ± 2.52 | 42.8 ± 1.26 | 26.1 ± 1.33 | 33.5 ± 2.15 | 31.7 ± 0.50 | 31.7 ± 1.53 |
| N/P | control | 5.42 ± 1.00 | 32.0 ± 6.25 | 8.26 ± 3.42 | 3.29 ± 0.81 | 30.2 ± 2.99 | 47.9 ± 6.69 |
| | track | 3.93 ± 0.75 | 28.5 ± 5.04 | 4.04 ± 0.87 | 13.2 ± 6.40 | 35.2 ± 2.83 | 50.7 ± 0.81 |
| $NO_3$ = $NO_2$ (ppm) | track | 1497 ± 106 | 2380 ± 241 | 2118 ± 645 | 766 ± 96.8 | 1166 ± 93.4 | 2112 ± 0.56 |
| | control | 0.88 ± 0.31 | 2.00 ± 0.29 | 0.35 ± 0.10 | 0.96 ± 0.08 | 0.96 ± 0.23 | 2.40 ± 1.56 |
| $NH_4$ (ppm) | track | 0.90 ± 0.18 | 2.60 ± 0.44 | 0.46 ± 0.07 | 0.63 ± 0.04 | 1.08 ± 0.27 | 4.01 ± 0.21 |
| | control | 0.19 ± 0.16 | 0.92 ± 0.04 | 0.24 ± 0.02 | 1.28 ± 0.10 | 0.58 ± 0.11 | 0.38 ± 0.12 |
| | track | 0.06 ± 0.03 | 0.93 ± 0.23 | 0.31 ± 0.09 | 1.10 ± 0.08 | 0.96 ± 0.20 | 0.66 |

**Soil chemistry, 0-0.5 cm**

| Coleogyne | | 20-year sites | | 40-year sites | | | |
|---|---|---|---|---|---|---|---|
| | | CORA1 | CORA2 | CORA3 | CORA4 | CORA5 | CORA6 |
| | | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE | Mean ± SE |
| P (ppm) | control | 6.50 ± 0.88 | 5.50 ± 0.92 | 9.37 ± 0.95 | 9.49 ± 1.31 | 10.6 ± 1.47 | 10.4 ± 0.89 |
| | track | 5.81 ± 0.33 | 7.09 ± 1.68 | 12.3 ± 3.78 | 9.74 ± 1.84 | 9.22 ± 1.41 | 13.0 ± 4.14 |
| $K_{av}$ (ppm) | control | 134 ± 11.2 | 76.8 ± 3.20 | 127 ± 22.2 | 161 ± 20.4 | 111 ± 13.9 | 97.1 ± 5.94 |
| | track | 132 ± 3.85 | 78.9 ± 5.33 | 101 ± 19.9 | 155 ± 1.07 | 98.1 ± 34.1 | 103 ± 10.8 |
| OM (%) | control | 1.18 ± 0.51 | 0.70 ± 0.01 | 1.81 ± 0.16 | 0.79 ± 0.18 | 0.55 ± 0.07 | 0.92 ± 0.22 |
| | track | 0.81 ± 0.38 | 0.66 ± 0.14 | 0.84 ± 0.31 | 0.35 ± 0.05 | 1.15 ± 0.18 | 1.44 ± 0.66 |
| pH | control | 7.44 ± 0.16 | 7.03 ± 0.20 | 6.82 ± 0.08 | 6.79 ± 0.06 | 7.16 ± 0.01 | 7.09 ± 0.03 |
| | track | 7.58 ± 0.06 | 7.49 ± 0.02 | 6.82 ± 0.10 | 6.93 ± 0.04 | 7.12 ± 0.18 | 7.03 ± 0.04 |
| CEC (meq/100 g) | control | 5.14 ± 0.46 | 2.65 ± 0.03 | 2.52 ± 0.29 | 3.51 ± 0.28 | 2.55 ± 0.34 | 4.20 ± 0.60 |
| | track | 5.29 ± 0.35 | 2.49 ± 0.05 | 3.81 ± 0.39 | 2.80 ± 0.19 | 6.19 ± 1.79 | 3.94 ± 0.30 |
| Zn (ppm) | control | 0.45 ± 0.02 | 0.60 ± 0.02 | 0.47 ± 0.04 | 0.29 ± 0.02 | 0.28 ± 0.02 | 0.49 ± 0.08 |
| | track | 0.42 ± 0.05 | 0.60 ± 0.02 | 0.38 ± 0.02 | 0.23 ± 0.02 | 0.27 ± 0.02 | 0.35 ± 0.05 |
| Fe (ppm) | control | 1.47 ± 0.05 | 6.77 ± 0.63 | 3.31 ± 0.19 | 2.14 ± 0.23 | 3.14 ± 0.14 | 4.12 ± 0.31 |
| | track | 1.25 ± 0.03 | 5.66 ± 0.24 | 3.77 ± 0.23 | 1.57 ± 0.10 | 3.16 ± 0.12 | 3.87 ± 0.08 |
| Mn (ppm) | control | 4.77 ± 0.27 | 5.35 ± 0.68 | 3.84 ± 0.12 | 2.27 ± 0.27 | 2.72 ± 0.08 | 6.35 ± 1.77 |
| | track | 4.14 ± 0.54 | 5.16 ± 0.64 | 3.31 ± 0.10 | 1.50 ± 0.11 | 2.86 ± 0.04 | 3.81 ± 0.54 |
| Cu (ppm) | control | 0.31 ± 0.01 | 0.38 ± 0.02 | 0.34 ± 0.02 | 0.29 ± 0.02 | 0.28 ± 0.01 | 0.41 ± 0.03 |
| | track | 0.30 ± 0.03 | 0.40 ± 0.01 | 0.36 ± 0.02 | 0.25 ± 0.03 | 0.29 ± 0.01 | 0.37 ± 0.03 |
| $Ca_{ex}$ (ppm) | control | 2458 ± 117 | 2265 ± 51.0 | 1907 ± 53.3 | 2265 ± 141 | 2022 ± 84.0 | 1850 ± 364 |
| | track | 2364 ± 74.2 | 2204 ± 39.0 | 2215 ± 75.1 | 2035 ± 53.25 | 2116 ± 114 | 2567 ± 201 |
| $Mg_{ex}$ (ppm) | control | 72.7 ± 4.00 | 66.2 ± 3.00 | 68.4 ± 5.51 | 90.0 ± 9.34 | 60.5 ± 2.45 | 90.1 ± 6.24 |
| | track | 66.8 ± 4.19 | 60.4 ± 3.51 | 62.4 ± 6.58 | 81.4 ± 6.24 | 47.9 ± 3.05 | 80.3 ± 2.51 |
| $K_{ex}$ (ppm) | control | 92.0 ± 3.16 | 85.3 ± 3.39 | 105 ± 4.11 | 119 ± 11.9 | 111 ± 0.93 | 118 ± 3.84 |
| | track | 87.7 ± 2.75 | 89.9 ± 1.05 | 84.7 ± 7.58 | 88.2 ± 3.98 | 95.0 ± 12.1 | 120 ± 12.7 |
| $Na_{ex}$ (ppm) | control | 66.1 ± 5.20 | 61.9 ± 3.30 | 57.9 ± 4.52 | 48.9 ± 3.06 | 44.2 ± 4.97 | 38.3 ± 4.46 |
| | track | 62.8 ± 2.23 | 58.5 ± 0.87 | 39.8 ± 2.91 | 48.1 ± 0.27 | 41.7 ± 1.87 | 52.6 ± 5.66 |
| Total N (ppm) | control | 320 ± 10.3 | 673 ± 87.2 | 280 ± 22.9 | 133 ± 11.1 | 274 ± 30.3 | 39.4 ± 12.5 |
| | track | 280 ± 30.7 | 284 ± 44.7 | 189 ± 7.07 | 133 ± 47.1 | 154 ± 3.15 | 69.1 ± 53.7 |
| ANP (%) | control | 5.89 ± 0.55 | 2.71 ± 0.01 | 3.91 ± 0.28 | 10.4 ± 0.48 | 4.56 ± 0.07 | 2.34 ± 0.39 |
| | track | 5.81 ± 0.29 | 2.52 ± 0.06 | 6.55 ± 0.38 | 10.6 ± 0.48 | 3.67 ± 0.31 | 4.08 ± 0.47 |
| Very Coarse | control | 2.65 ± 1.01 | 0.11 ± 0.01 | 0.26 ± 0.05 | 0.16 ± 0.03 | 0.19 ± 0.04 | 0.08 ± 0.01 |
| | track | 3.58 ± 0.76 | 0.18 ± 0.03 | 0.71 ± 0.10 | 0.14 ± 0.06 | 0.16 ± 0.04 | 0.15 ± 0.06 |
| Coarse | control | 11.7 ± 2.36 | 0.30 ± 0.09 | 0.30 ± 0.01 | 0.34 ± 0.06 | 0.57 ± 0.07 | 0.14 ± 0.00 |
| | track | 14.1 ± 1.23 | 0.27 ± 0.02 | 0.62 ± 0.15 | 0.54 ± 0.35 | 0.54 ± 0.06 | 0.20 ± 0.06 |
| Medium | control | 20.1 ± 3.77 | 5.42 ± 0.43 | 3.58 ± 0.78 | 2.18 ± 0.26 | 6.52 ± 0.70 | 1.73 ± 0.37 |
| | track | 23.4 ± 1.23 | 6.72 ± 0.66 | 8.61 ± 4.38 | 1.91 ± 0.18 | 8.79 ± 0.80 | 2.13 ± 0.45 |
| Fine | control | 20.1 ± 2.88 | 65.0 ± 8.33 | 43.8 ± 3.56 | 25.8 ± 1.63 | 42.8 ± 3.21 | 34.9 ± 3.73 |
| | track | 28.0 ± 3.33 | 62.5 ± 1.66 | 42.4 ± 3.00 | 25.1 ± 1.85 | 53.2 ± 2.48 | 35.5 ± 3.73 |
| Very Fine | control | 7.53 ± 1.24 | 13.9 ± 7.91 | 34.7 ± 3.55 | 41.9 ± 1.56 | 32.1 ± 2.45 | 38.2 ± 2.79 |
| | track | 2.76 ± 2.75 | 16.6 ± 2.28 | 26.7 ± 2.84 | 39.5 ± 0.32 | 23.1 ± 2.00 | 33.6 ± 1.79 |
| Sand (%) | control | 78.8 ± 0.79 | 81.4 ± 0.91 | 80.6 ± 0.67 | 64.7 ± 0.77 | 77.1 ± 1.55 | 70.5 ± 2.19 |
| | track | 77.5 ± 1.28 | 81.4 ± 0.30 | 79.1 ± 1.09 | 68.6 ± 0.69 | 82.2 ± 1.20 | 69.2 ± 2.49 |
| Clay (%) | control | 9.25 ± 0.33 | 11.9 ± 0.67 | 14.9 ± 0.00 | 12.7 ± 0.59 | 10.6 ± 0.41 | 9.84 ± 0.58 |
| | track | 10.1 ± 0.62 | 10.5 ± 0.62 | 15.5 ± 0.67 | 14.1 ± 1.25 | 9.48 ± 0.58 | 10.2 ± 0.86 |
| Silt (%) | control | 12.0 ± 0.47 | 6.68 ± 1.37 | 4.51 ± 0.67 | 22.5 ± 0.29 | 12.2 ± 1.28 | 19.7 ± 2.19 |
| | track | 12.4 ± 1.35 | 8.09 ± 0.56 | 5.36 ± 0.95 | 17.3 ± 1.87 | 8.31 ± 1.20 | 20.5 ± 2.85 |
| N/P | control | 50.7 ± 5.74 | 120 ± 41.83 | 30.1 ± 0.84 | 14.2 ± 0.98 | 26.0 ± 1.04 | 4.03 ± 1.60 |
| | track | 48.3 ± 4.70 | 43.9 ± 12.0 | 17.7 ± 3.94 | 17.4 ± 10.0 | 17.4 ± 2.01 | 6.74 ± 5.78 |
| $NO_3 = NO_2$ (ppm) | control | 0.23 ± 0.05 | 0.20 ± 0.02 | 0.23 ± 0.06 | 0.25 ± 0.01 | 0.20 ± 0.02 | 0.18 ± 0.02 |
| | track | 0.21 ± 0.03 | 0.11 ± 0.06 | 0.18 ± 0.02 | 0.25 ± 0.00 | 0.25 ± 0.03 | 0.26 ± 0.05 |
| $NH_4$ (ppm) | control | 0.31 ± 0.03 | 0.39 ± 0.11 | 0.49 ± 0.08 | 0.24 ± 0.06 | 0.30 ± 0.02 | 0.44 ± 0.07 |
| | track | 0.24 ± 0.04 | 0.17 ± 0.11 | 0.33 ± 0.08 | 0.14 ± 0.02 | 0.32 ± 0.05 | 0.45 ± 0.05 |

**Soil chemistry, 0-10 cm**

| **Artemisia** | | **20-year sites** | | | **40-year sites** | | |
|---|---|---|---|---|---|---|---|
| | | **ATSP1** | **ATSP2** | **ATSP3** | **ATSP4** | **ATSP5** | **ATSP6** |
| | | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** |
| P (ppm) | control | 11.5 ± 1.08 | 14.23 ± 0.73 | 10.1 ± 1.03 | 9.85 ± 2.46 | 8.66 ± 0.66 | 7.47 ± 0.40 |
| | track | 10.6 ± 1.06 | 13.60 ± 0.47 | 8.05 ± 0.49 | 10.4 ± 0.47 | 8.64 ± 0.55 | 7.70 ± 0.65 |
| $K_{av}$ (ppm) | control | 97.1 ± 5.94 | 131 ± 12.9 | 129 ± 11.1 | 125 ± 34.2 | 103 ± 11.88 | 84 ± 4.27 |
| | track | 93.9 ± 19.2 | 104.53 ± 2.82 | 97.1 ± 8.33 | 96.00 ± 15.1 | 109.87 ± 17.17 | 90.7 ± 1.07 |
| OM (%) | control | 2.52 ± 1.85 | 1.20 ± 0.230 | 1.02 ± 0.16 | 1.46 ± 0.310 | 0.717 ± 0.02 | 0.807 ± 0.174 |
| | track | 0.54 ± 0.06 | 0.64 ± 0.05 | 0.82 ± 0.13 | 1.00 ± 0.27 | 0.626 ± 0.07 | 0.571 ± 0.063 |
| pH | control | 7.08 ± 0.05 | 6.85 ± 0.04 | 7.26 ± 0.02 | 6.88 ± 0.17 | 7.90 ± 0.10 | 7.72 ± 0.087 |
| | track | 7.05 ± 0.07 | 6.83 ± 0.11 | 7.22 ± 0.05 | 6.99 ± 0.15 | 7.84 ± 0.10 | 7.74 ± 0.111 |
| CEC (meq/100 g) | control | 4.74 ± 0.58 | 6.07 ± 0.58 | 6.68 ± 0.39 | 4.74 ± 1.22 | 4.78 ± 0.45 | 5.75 ± 0.565 |
| | track | 5.13 ± 0.70 | 6.10 ± 0.33 | 6.03 ± 0.31 | 4.65 ± 1.25 | 4.58 ± 0.79 | 6.014 ± 0.261 |
| Zn (ppm) | control | 0.22 ± 0.02 | 0.35 ± 0.02 | 0.24 ± 0.01 | 0.35 ± 0.01 | 0.45 ± 0.05 | 0.460 ± 0.045 |
| | track | 0.23 ± 0.01 | 0.29 ± 0.02 | 0.23 ± 0.01 | 0.27 ± 0.05 | 0.42 ± 0.02 | 0.514 ± 0.022 |
| Fe (ppm) | control | 1.96 ± 0.17 | 2.09 ± 0.04 | 1.32 ± 0.05 | 2.53 ± 0.46 | 1.35 ± 0.23 | 1.28 ± 0.117 |
| | track | 2.21 ± 0.30 | 1.69 ± 0.06 | 1.30 ± 0.08 | 2.09 ± 0.33 | 1.27 ± 0.13 | 1.30 ± 0.091 |
| Mn (ppm) | control | 3.57 ± 0.43 | 4.20 ± 0.25 | 3.11 ± 0.16 | 4.87 ± 0.37 | 4.24 ± 0.39 | 4.12 ± 0.066 |
| | track | 4.51 ± 0.45 | 4.04 ± 0.22 | 2.98 ± 0.34 | 4.19 ± 0.41 | 3.51 ± 0.18 | 3.97 ± 0.504 |
| Cu (ppm) | control | 0.25 ± 0.03 | 0.40 ± 0.02 | 0.29 ± 0.02 | 0.28 ± 0.01 | 0.45 ± 0.06 | 0.42 ± 0.03 |
| | track | 0.28 ± 0.03 | 0.40 ± 0.02 | 0.35 ± 0.01 | 0.30 ± 0.01 | 0.40 ± 0.03 | 0.44 ± 0.03 |
| $Ca_{ex}$ (ppm) | control | 1663 ± 331 | 1490 ± 375 | 2548 ± 444 | 1568 ± 639 | 1944 ± 364 | 1703 ± 234 |
| | track | 2733 ± 343 | 1690 ± 569 | 2625 ± 197 | 1792 ± 780 | 2232 ± 379 | 1701 ± 435 |
| $Mg_{ex}$ (ppm) | control | 145 ± 24.1 | 193 ± 11.65 | 201 ± 14.9 | 150 ± 15.9 | 153 ± 34.3 | 195 ± 24.5 |
| | track | 147 ± 17.0 | 196 ± 6.62 | 192 ± 11.99 | 147 ± 16.8 | 159 ± 37.3 | 167 ± 21.1 |
| $K_{ex}$ (ppm) | control | 143 ± 8.74 | 188 ± 13.9 | 186 ± 16.4 | 154 ± 37.1 | 144 ± 17.5 | 121 ± 6.09 |
| | track | 145 ± 18.2 | 160 ± 2.55 | 155 ± 9.83 | 138 ± 22.4 | 151 ± 23.7 | 124 ± 13.5 |
| $Na_{ex}$ (ppm) | control | 61.6 ± 4.72 | 65.1 ± 0.96 | 45.8 ± 1.81 | 43.1 ± 6.44 | 60.9 ± 1.18 | 25.2 ± 8.91 |
| | track | 62.7 ± 1.44 | 60.1 ± 0.77 | 64.4 ± 3.20 | 43.5 ± 2.75 | 16.7 ± 0.70 | 17.5 ± 0.90 |
| Total N (ppm) | control | 71.5 ± 43.8 | 93.5 ± 50.3 | 88.0 ± 41.4 | 105 ± 37.0 | 300 ± 46.6 | 340 ± 49.1 |
| | track | 33.2 ± 21.5 | 40.0 ± 5.01 | 20.3 ± 2.31 | 69.4 ± 36.9 | 312 ± 35.6 | 270 ± 14.8 |
| ANP (%) | control | 1.63 ± 0.36 | 1.48 ± 0.16 | 2.54 ± 0.54 | 2.89 ± 2.11 | 1.43 ± 0.68 | 0.87 ± 0.03 |
| | track | 2.27 ± 0.27 | 1.53 ± 0.27 | 2.34 ± 0.28 | 3.27 ± 2.20 | 1.72 ± 0.64 | 0.81 ± 0.02 |
| Very Coarse | control | 0.04 ± 0.02 | 0.12 ± 0.05 | 0.06 ± 0.01 | 0.14 ± 0.09 | 0.02 ± 0.01 | 0.05 ± 0.01 |
| | track | 0.05 ± 0.01 | 0.04 ± 0.01 | 0.01 ± 0.00 | 0.14 ± 0.13 | 0.05 ± 0.02 | 0.07 ± 0.05 |
| Coarse | control | 0.05 ± 0.01 | 0.10 ± 0.01 | 0.07 ± 0.01 | 0.12 ± 0.08 | 0.05 ± 0.01 | 0.07 ± 0.01 |
| | track | 0.03 ± 0.01 | 0.07 ± 0.01 | 0.05 ± 0.00 | 0.16 ± 0.11 | 0.07 ± 0.02 | 0.08 ± 0.01 |
| Medium | control | 0.92 ± 0.25 | 1.24 ± 0.16 | 0.99 ± 0.11 | 4.31 ± 0.58 | 0.61 ± 0.19 | 0.32 ± 0.03 |
| | track | 1.01 ± 0.09 | 1.12 ± 0.12 | 1.08 ± 0.09 | 4.33 ± 0.41 | 0.67 ± 0.27 | 0.40 ± 0.04 |
| Fine | control | 40.2 ± 5.74 | 33.4 ± 1.25 | 27.9 ± 1.00 | 40.1 ± 8.06 | 34.0 ± 11.2 | 29.1 ± 2.38 |
| | track | 37.2 ± 4.23 | 31.6 ± 1.82 | 28.5 ± 0.93 | 39.7 ± 7.81 | 34.9 ± 9.81 | 31.7 ± 1.73 |
| Very Fine | control | 34.7 ± 2.75 | 30.3 ± 0.71 | 27.4 ± 1.65 | 25.3 ± 2.80 | 33.9 ± 4.94 | 33.7 ± 2.05 |
| | track | 34.6 ± 1.49 | 29.3 ± 0.41 | 26.6 ± 1.93 | 22.5 ± 1.90 | 32.9 ± 3.56 | 31.7 ± 0.37 |
| Sand (%) | control | 72.4 ± 2.91 | 64.7 ± 0.72 | 62.1 ± 1.40 | 72.5 ± 5.60 | 70.7 ± 5.35 | 66.3 ± 3.77 |
| | track | 70.9 ± 2.03 | 64.1 ± 0.55 | 62.2 ± 0.41 | 70.3 ± 4.93 | 68.4 ± 4.67 | 66.1 ± 0.48 |
| Clay (%) | control | 10.3 ± 1.59 | 10.9 ± 0.58 | 12.6 ± 0.33 | 10.8 ± 1.26 | 12.0 ± 0.87 | 14.4 ± 1.86 |
| | track | 11.9 ± 1.52 | 11.6 ± 0.48 | 13.7 ± 0.59 | 11.5 ± 1.78 | 13.8 ± 0.58 | 14.0 ± 0.73 |
| Silt (%) | control | 17.3 ± 1.76 | 24.3 ± 0.33 | 25.3 ± 1.24 | 16.7 ± 4.43 | 17.2 ± 4.52 | 19.4 ± 1.92 |
| | track | 17.2 ± 0.52 | 24.3 ± 0.33 | 24.1 ± 0.33 | 18.3 ± 3.50 | 17.7 ± 4.10 | 19.9 ± 0.52 |
| N/P | control | 6.12 ± 3.85 | 6.61 ± 3.55 | 8.73 ± 3.64 | 13.5 ± 5.73 | 34.9 ± 5.05 | 46.5 ± 9.43 |
| | track | 2.79 ± 1.71 | 2.94 ± 0.36 | 2.58 ± 0.46 | 6.99 ± 3.81 | 36.2 ± 4.28 | 35.6 ± 3.96 |
| $NO_3 = NO_2$ (ppm) | control | 0.08 ± 0.02 | 0.06 ± 0.01 | 0.10 ± 0.01 | 0.05 ± 0.02 | 0.04 ± 0.02 | 0.02 ± 0.01 |
| | track | 0.05 ± 0.02 | 0.05 ± 0.01 | 0.02 ± 0.00 | 0.07 ± 0.04 | 0.04 ± 0.02 | 0.01 ± 0.01 |
| $NH_4$ (ppm) | control | 0.08 ± 0.04 | 0.00 ± 0.00 | 0.11 ± 0.03 | 0.10 ± 0.01 | 0.06 ± 0.03 | 0.11 ± 0.01 |
| | track | 0.09 ± 0.04 | 0.00 ± 0.00 | 0.05 ± 0.02 | 0.19 ± 0.03 | 0.08 ± 0.03 | 0.09 ± 0.05 |

## Soil chemistry, 0-10 cm

| **Atriplex** | | **20-year sites** | | | **40-year sites** | | |
|---|---|---|---|---|---|---|---|
| | | **ARTR1** | **ARTR2** | **ARTR3** | **ARTR4** | **ARTR5** | **ARTR6** |
| | | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** | **Mean ± SE** |
| P (ppm) | control | 6.64 ± 2.25 | 13.8 ± 1.91 | 6.97 ± 1.35 | 14.39 ± 0.53 | 9.38 ± 1.11 | 11.69 ± 0.22 |
| | track | 8.63 ± 1.02 | 19.4 ± 0.94 | 9.49 ± 1.56 | 12.67 ± 0.69 | 12.71 ± 2.01 | 13.00 ± 1.13 |
| $K_{av}$ (ppm) | control | 134 ± 15.1 | 245 ± 28.2 | 149 ± 10.67 | 141 ± 20.57 | 95 ± 20.35 | 143 ± 7.47 |
| | track | 154 ± 14.4 | 226 ± 17.5 | 171 ± 10.67 | 83 ± 10.29 | 90 ± 19.55 | 135 ± 16.66 |
| OM (%) | control | 1.94 ± 0.16 | 1.91 ± 0.25 | 0.85 ± 0.31 | 1.27 ± 0.05 | 1.22 ± 0.11 | 1.26 ± 0.09 |
| | track | 1.94 ± 0.01 | 2.10 ± 0.08 | 1.57 ± 0.03 | 0.81 ± 0.23 | 1.57 ± 0.10 | 1.18 ± 0.04 |
| pH | control | 7.54 ± 0.05 | 8.01 ± 0.05 | 7.66 ± 0.01 | 7.99 ± 0.03 | 7.91 ± 0.17 | 8.31 ± 0.07 |
| | track | 7.68 ± 0.03 | 7.84 ± 0.04 | 7.58 ± 0.05 | 7.78 ± 0.07 | 7.88 ± 0.03 | 8.21 ± 0.05 |
| CEC (meq/100 g) | control | 24.2 ± 9.82 | 9.86 ± 0.54 | 17.28 ± 3.18 | 5.54 ± 0.66 | 6.30 ± 0.10 | 5.52 ± 0.54 |
| | track | 37.6 ± 9.92 | 38.7 ± 1.64 | 35.29 ± 11.89 | 4.93 ± 1.14 | 6.48 ± 1.44 | 5.78 ± 0.81 |
| Zn (ppm) | control | 0.47 ± 0.00 | 0.41 ± 0.06 | 0.55 ± 0.03 | 0.38 ± 0.00 | 0.36 ± 0.05 | 0.45 ± 0.03 |
| | track | 0.64 ± 0.11 | 0.45 ± 0.07 | 0.50 ± 0.08 | 0.49 ± 0.04 | 0.40 ± 0.05 | 0.55 ± 0.15 |
| Fe (ppm) | control | 0.71 ± 0.16 | 0.96 ± 0.11 | 0.39 ± 0.05 | 1.89 ± 0.10 | 1.82 ± 0.07 | 2.78 ± 0.09 |
| | track | 0.86 ± 0.14 | 1.32 ± 0.12 | 0.27 ± 0.03 | 2.19 ± 0.12 | 4.15 ± 2.10 | 3.34 ± 0.50 |
| Mn (ppm) | control | 0.89 ± 0.34 | 1.42 ± 0.16 | 0.63 ± 0.04 | 3.63 ± 0.19 | 3.30 ± 0.30 | 2.85 ± 0.40 |
| | track | 0.96 ± 0.20 | 1.61 ± 0.09 | 0.52 ± 0.05 | 3.67 ± 0.03 | 3.28 ± 0.73 | 3.64 ± 0.36 |
| Cu (ppm) | control | 0.53 ± 0.07 | 1.30 ± 0.44 | 1.25 ± 0.15 | 0.60 ± 0.06 | 1.17 ± 0.52 | 0.97 ± 0.18 |
| | track | 0.51 ± 0.01 | 1.20 ± 0.41 | 0.84 ± 0.23 | 1.26 ± 0.12 | 0.89 ± 0.06 | 1.38 ± 0.46 |
| $Ca_{ex}$ (ppm) | control | 29257 ± 8669 | 2907 ± 23.0 | 18992 ± 4560 | 2515 ± 96.67 | 5079 ± 2891 | 1803 ± 45.69 |
| | track | 31761 ± 8568 | 2721 ± 92.1 | 28553 ± 1498 | 2677 ± 79.53 | 2501 ± 66.83 | 1848 ± 99.28 |
| $Mg_{ex}$ (ppm) | control | 150 ± 36.8 | 252 ± 17.5 | 147 ± 3.73 | 206 ± 14.23 | 185 ± 11.22 | 183 ± 14.26 |
| | track | 161 ± 24.1 | 238 ± 10.9 | 105 ± 9.64 | 207 ± 15.08 | 221 ± 37.97 | 168 ± 21.97 |
| $K_{ex}$ (ppm) | control | 196 ± 53.9 | 223 ± 28.3 | 198 ± 3.51 | 195 ± 17.27 | 173 ± 8.45 | 193 ± 4.13 |
| | track | 187 ± 16.4 | 284 ± 14.9 | 164 ± 3.40 | 168 ± 7.92 | 174 ± 18.8 | 176 ± 9.62 |
| $Na_{ex}$ (ppm) | control | 164 ± 39.7 | 221 ± 60.8 | 99.5 ± 14.8 | 172 ± 10.4 | 101 ± 22.7 | 290 ± 22.7 |
| | track | 270 ± 67.4 | 172 ± 28.3 | 90.9 ± 5.02 | 134 ± 9.55 | 149 ± 21.3 | 194 ± 49.3 |
| Total N (ppm) | control | 77.8 ± 16.0 | 161 ± 28.3 | 39.4 ± 6.96 | 360 ± 33.9 | 364 ± 25.4 | 275 ± 36.7 |
| | track | 87.8 ± 21.3 | 168 ± 47.3 | 51.3 ± 24.6 | 324 ± 24.7 | 324 ± 13.2 | 350 ± 18.5 |
| ANP (%) | control | 11.6 ± 5.23 | 18.2 ± 0.27 | 15.8 ± 1.25 | 7.03 ± 0.13 | 6.68 ± 0.40 | 5.95 ± 0.35 |
| | track | 12.3 ± 4.46 | 17.7 ± 0.35 | 14.5 ± 0.36 | 12.4 ± 2.46 | 9.14 ± 1.66 | 5.94 ± 0.52 |
| Very Coarse | control | 1.23 ± 0.48 | 0.05 ± 0.01 | 0.34 ± 0.07 | 1.33 ± 0.18 | 1.87 ± 0.27 | 1.05 ± 0.31 |
| | track | 1.02 ± 0.20 | 0.03 ± 0.01 | 0.38 ± 0.14 | 2.21 ± 0.35 | 2.05 ± 0.50 | 1.11 ± 0.11 |
| Coarse | control | 1.63 ± 0.36 | 0.08 ± 0.03 | 0.61 ± 0.09 | 2.09 ± 0.04 | 1.80 ± 0.16 | 1.30 ± 0.21 |
| | track | 1.43 ± 0.09 | 0.06 ± 0.01 | 0.59 ± 0.17 | 3.08 ± 0.35 | 2.18 ± 0.36 | 1.45 ± 0.17 |
| Medium | control | 2.54 ± 0.15 | 0.15 ± 0.05 | 2.37 ± 1.53 | 5.60 ± 0.34 | 3.43 ± 0.30 | 4.25 ± 0.42 |
| | track | 2.40 ± 0.45 | 0.13 ± 0.02 | 1.63 ± 0.34 | 6.96 ± 0.83 | 5.00 ± 0.88 | 5.58 ± 0.52 |
| Fine | control | 11.0 ± 0.69 | 2.21 ± 0.29 | 11.3 ± 1.59 | 15.7 ± 1.11 | 11.5 ± 2.64 | 15.8 ± 0.68 |
| | track | 9.84 ± 2.22 | 1.43 ± 0.49 | 10.6 ± 0.92 | 17.4 ± 0.91 | 16.4 ± 2.12 | 19.4 ± 2.02 |
| Very Fine | control | 9.82 ± 0.99 | 7.01 ± 0.84 | 17.1 ± 7.18 | 20.5 ± 2.63 | 15.6 ± 2.56 | 17.4 ± 4.03 |
| | track | 12.7 ± 2.55 | 4.68 ± 0.94 | 18.7 ± 1.57 | 17.0 ± 2.02 | 16.3 ± 1.15 | 19.9 ± 2.85 |
| Sand (%) | control | 41.3 ± 1.45 | 67.5 ± 1.76 | 41.5 ± 3.18 | 52.4 ± 1.89 | 54.2 ± 8.72 | 59.9 ± 5.43 |
| | track | 42.6 ± 0.70 | 70.5 ± 8.17 | 44.1 ± 2.05 | 54.8 ± 1.73 | 50.2 ± 2.31 | 56.1 ± 4.04 |
| Clay (%) | control | . . | 15.2 ± 1.45 | 8.17 ± 3.84 | 17.2 ± 2.40 | 19.8 ± 5.29 | 15.1 ± 2.44 |
| | track | . . | 11.7 ± 1.16 | 7.65 ± 0.91 | 16.8 ± 1.15 | 20.5 ± 4.06 | 17.2 ± 2.40 |
| Silt (%) | control | . . | 17.3 ± 0.33 | 50.3 ± 4.67 | 30.5 ± 0.53 | 26.0 ± 4.00 | 25.0 ± 3.72 |
| | track | . . | 17.8 ± 9.16 | 48.3 ± 1.15 | 28.4 ± 1.53 | 29.3 ± 1.76 | 26.7 ± 1.82 |
| N/P | control | 19.8 ± 11.9 | 11.6 ± 1.34 | 5.7 ± 0.51 | 25.1 ± 2.41 | 39.3 ± 1.94 | 23.6 ± 3.46 |
| | track | 11.0 ± 3.83 | 8.48 ± 2.02 | 6.23 ± 3.69 | 25.5 ± 0.75 | 26.8 ± 4.11 | 27.4 ± 3.27 |
| $NO_3$ = $NO_2$ (ppm) | control | 0.68 ± 0.16 | 2.35 ± 0.61 | 0.13 ± 0.04 | 0.35 ± 0.08 | 0.59 ± 0.13 | 1.95 ± 0.19 |
| | track | 0.91 ± 0.26 | 1.14 ± 0.12 | 0.13 ± 0.03 | 0.25 ± 0.01 | 0.86 ± 0.17 | 1.86 ± 0.17 |
| $NH_4$ (ppm) | control | 0.13 ± 0.07 | 0.08 ± 0.03 | 0.00 ± 0.00 | 0.13 ± 0.08 | 0.13 ± 0.02 | 0.33 ± 0.25 |
| | track | 0.12 ± 0.12 | 0.15 ± 0.04 | 0.00 ± 0.00 | 0.15 ± 0.04 | 0.20 ± 0.05 | 0.03 ± 0.03 |

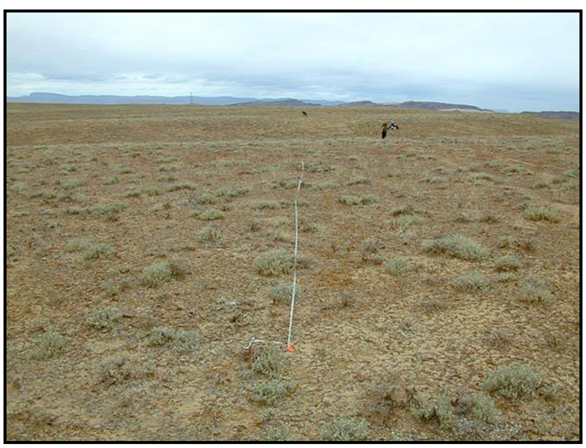
## Soil chemistry, 0-10 cm

| **Coleogyne** | | **20-year sites** | | **40-year sites** | | | |
|---|---|---|---|---|---|---|---|
| | | **CORA1** | **CORA2** | **CORA3** | **CORA4** | **CORA5** | **CORA6** |
| | | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** | **Mean** ± **SE** |
| P (ppm) | control | 5.93 ± 0.32 | 4.82 ± 0.68 | 10.7 ± 0.68 | 7.68 ± 1.11 | 16.3 ± 1.06 | 10.1 ± 0.34 |
| | track | 5.37 ± 0.14 | 5.49 ± 0.44 | 9.04 ± 0.59 | 7.58 ± 1.32 | 19.1 ± 3.46 | 11.5 ± 0.77 |
| $K_{av}$ (ppm) | track | 133 ± 7.47 | 87.5 ± 11.3 | 125 ± 1.85 | 173 ± 30.5 | 211 ± 16.1 | 80.0 ± 4.89 |
| | control | 151 ± 5.94 | 84.3 ± 4.65 | 86.4 ± 6.66 | 220 ± 45.9 | 292 ± 53.9 | 76.8 ± 4.89 |
| OM (%) | track | 0.19 ± 0.10 | 1.80 ± 0.11 | 0.23 ± 0.01 | 0.30 ± 0.10 | 0.66 ± 0.06 | 0.58 ± 0.06 |
| | control | 0.35 ± 0.07 | 0.87 ± 0.41 | 0.17 ± 0.05 | 0.22 ± 0.10 | 0.72 ± 0.19 | 0.47 ± 0.03 |
| pH | track | 7.76 ± 0.02 | 7.51 ± 0.07 | 7.49 ± 0.04 | 7.74 ± 0.06 | 7.71 ± 0.02 | 7.28 ± 0.01 |
| | control | 7.68 ± 0.01 | 7.78 ± 0.14 | 7.38 ± 0.02 | 7.77 ± 0.07 | 7.66 ± 0.03 | 7.29 ± 0.04 |
| CEC (meq/100 g) | track | 6.74 ± 0.68 | 2.29 ± 0.25 | 1.45 ± 0.31 | 2.29 ± 0.25 | 1.70 ± 0.05 | 4.17 ± 0.25 |
| | control | 7.54 ± 0.77 | 1.72 ± 0.10 | 2.29 ± 0.54 | 2.14 ± 0.19 | 1.41 ± 0.28 | 4.39 ± 0.15 |
| Zn (ppm) | track | 0.57 ± 0.06 | 0.41 ± 0.02 | 0.25 ± 0.01 | 0.16 ± 0.02 | 0.27 ± 0.03 | 0.20 ± 0.01 |
| | control | 0.58 ± 0.09 | 0.49 ± 0.01 | 0.17 ± 0.01 | 0.17 ± 0.00 | 0.22 ± 0.03 | 0.18 ± 0.01 |
| Fe (ppm) | track | 2.56 ± 0.08 | 2.40 ± 0.17 | 1.86 ± 0.18 | 0.74 ± 0.08 | 1.44 ± 0.16 | 1.30 ± 0.07 |
| | control | 1.60 ± 0.72 | 3.96 ± 0.72 | 2.08 ± 0.54 | 0.95 ± 0.18 | 2.36 ± 0.83 | 1.18 ± 0.08 |
| Mn (ppm) | track | 2.26 ± 0.08 | 4.11 ± 0.22 | 2.34 ± 0.17 | 1.26 ± 0.13 | 1.72 ± 0.30 | 2.37 ± 0.08 |
| | control | 2.64 ± 0.12 | 4.23 ± 0.31 | 2.74 ± 0.53 | 1.24 ± 0.04 | 1.54 ± 0.19 | 2.28 ± 0.20 |
| Cu (ppm) | track | 0.27 ± 0.02 | 0.25 ± 0.01 | 0.14 ± 0.01 | 0.12 ± 0.03 | 0.19 ± 0.02 | 0.23 ± 0.01 |
| | control | 0.44 ± 0.13 | 0.30 ± 0.02 | 0.14 ± 0.01 | 0.16 ± 0.04 | 0.15 ± 0.03 | 0.28 ± 0.02 |
| $Ca_{ex}$ (ppm) | track | 2896 ± 93.6 | 2309 ± 18.99 | 1913 ± 42.1 | 2103 ± 56.3 | 1966 ± 44.4 | 2613 ± 99.7 |
| | control | 2968 ± 156 | 2347 ± 62.3 | 2210 ± 152 | 2031 ± 44.1 | 1995 ± 44.8 | 2951 ± 61.3 |
| $Mg_{ex}$ (ppm) | track | 81.7 ± 3.70 | 65.8 ± 3.62 | 61.8 ± 7.39 | 86.3 ± 6.82 | 51.9 ± 3.21 | 122 ± 10.1 |
| | control | 88.3 ± 5.70 | 62.6 ± 4.68 | 69.5 ± 15.8 | 115 ± 8.65 | 38.3 ± 1.51 | 121 ± 4.65 |
| $K_{ex}$ (ppm) | track | 84.7 ± 0.36 | 89.7 ± 9.82 | 81.0 ± 3.81 | 116 ± 7.73 | 75.5 ± 3.72 | 140 ± 8.16 |
| | control | 100 ± 1.89 | 99.1 ± 6.75 | 78.0 ± 13.2 | 126 ± 12.99 | 64.1 ± 4.73 | 139 ± 5.11 |
| $Na_{ex}$ (ppm) | track | 62.3 ± 0.70 | 70.3 ± 2.60 | 46.5 ± 3.07 | 46.0 ± 7.39 | 47.5 ± 0.18 | 70.0 ± 3.72 |
| | control | 64.6 ± 4.24 | 65.3 ± 6.91 | 46.1 ± 6.18 | 49.9 ± 2.77 | 50.4 ± 3.45 | 61.5 ± 2.90 |
| Total N (ppm) | track | 268 ± 26.7 | 92.4 ± 4.19 | 53.5 ± 24.8 | 40.3 ± 3.55 | 87.1 ± 23.3 | 37.6 ± 11.1 |
| | control | 232 ± 8.82 | 98.5 ± 4.38 | 109 ± 19.6 | 60.4 ± 4.19 | 127 ± 9.39 | 72.5 ± 20.9 |
| ANP (%) | track | 7.24 ± 0.84 | 2.60 ± 0.17 | 4.45 ± 0.52 | 10.7 ± 0.29 | 4.09 ± 0.25 | 3.43 ± 0.18 |
| | control | 6.31 ± 0.61 | 2.56 ± 0.02 | 8.65 ± 1.83 | 10.4 ± 0.19 | 3.49 ± 0.16 | 6.07 ± 1.09 |
| Very Coarse | track | 2.51 ± 0.67 | 0.16 ± 0.06 | 0.21 ± 0.05 | 0.14 ± 0.02 | 0.05 ± 0.03 | 0.10 ± 0.04 |
| | control | 2.40 ± 0.45 | 0.25 ± 0.10 | 0.46 ± 0.13 | 0.08 ± 0.04 | 0.01 ± 0.00 | 0.12 ± 0.05 |
| Coarse | track | 11.6 ± 1.04 | 0.20 ± 0.01 | 0.21 ± 0.01 | 0.34 ± 0.17 | 0.59 ± 0.09 | 0.07 ± 0.03 |
| | control | 9.89 ± 0.37 | 0.30 ± 0.05 | 0.76 ± 0.07 | 0.20 ± 0.06 | 0.52 ± 0.04 | 0.25 ± 0.11 |
| Medium | track | 21.9 ± 1.02 | 5.99 ± 0.25 | 3.95 ± 0.88 | 2.60 ± 0.35 | 8.16 ± 0.95 | 1.73 ± 0.19 |
| | control | 18.2 ± 2.56 | 7.24 ± 0.53 | 9.93 ± 4.61 | 1.59 ± 0.14 | 9.86 ± 0.70 | 2.23 ± 0.57 |
| Fine | track | 23.7 ± 1.01 | 62.1 ± 3.37 | 55.6 ± 4.18 | 27.9 ± 1.12 | 47.5 ± 1.59 | 34.6 ± 3.39 |
| | control | 19.8 ± 4.38 | 63.9 ± 0.91 | 51.8 ± 2.51 | 22.2 ± 2.77 | 52.4 ± 3.76 | 32.7 ± 4.14 |
| Very Fine | track | 7.85 ± 0.54 | 17.7 ± 2.84 | 27.5 ± 4.42 | 37.0 ± 2.30 | 27.5 ± 0.44 | 36.7 ± 2.59 |
| | control | 7.29 ± 0.37 | 15.8 ± 0.23 | 18.6 ± 3.08 | 36.7 ± 0.83 | 22.4 ± 2.95 | 35.4 ± 3.31 |
| Sand (%) | track | 70.7 ± 0.29 | 82.4 ± 1.16 | 84.5 ± 0.39 | 70.7 ± 0.87 | 83.6 ± 1.33 | 68.3 ± 1.91 |
| | control | 72.1 ± 5.45 | 84.9 ± 0.67 | 81.0 ± 2.02 | 65.8 ± 1.99 | 86.9 ± 1.20 | 69.2 ± 0.68 |
| Clay (%) | track | 14.3 ± 0.67 | 12.6 ± 0.33 | 8.56 ± 0.00 | 14.3 ± 1.00 | 10.3 ± 0.00 | 10.7 ± 0.41 |
| | control | 13.6 ± 2.40 | 10.2 ± 1.69 | 9.89 ± 1.20 | 13.3 ± 0.89 | 9.61 ± 0.33 | 11.5 ± 0.29 |
| Silt (%) | track | 15.1 ± 0.77 | 5.01 ± 0.91 | 6.92 ± 0.39 | 15.0 ± 0.55 | 6.11 ± 1.33 | 21.0 ± 1.57 |
| | control | 14.3 ± 3.37 | 4.83 ± 1.03 | 9.13 ± 0.85 | 20.8 ± 2.73 | 3.44 ± 1.00 | 19.4 ± 0.62 |
| N/P | track | 45.3 ± 3.84 | 19.6 ± 1.70 | 4.81 ± 1.95 | 5.33 ± 0.32 | 5.26 ± 1.14 | 3.76 ± 1.11 |
| | control | 656 ± 128 | 1670 ± 858 | 189 ± 55.7 | 280 ± 94.5 | 441 ± 181 | 410 ± 24.8 |
| $NO_3$ = $NO_2$ (ppm) | track | 0.04 ± 0.01 | 0.04 ± 0.01 | 0.09 ± 0.03 | 0.16 ± 0.00 | 0.13 ± 0.00 | 0.09 ± 0.05 |
| | control | 0.04 ± 0.02 | 0.10 ± 0.04 | 0.07 ± 0.01 | 0.16 ± 0.01 | 0.15 ± 0.02 | 0.11 ± 0.01 |
| $NH_4$ (ppm) | track | 0.00 ± 0.00 | 0.01 ± 0.01 | 0.02 ± 0.01 | 0.00 ± 0.00 | 0.06 ± 0.02 | 0.11 ± 0.07 |
| | control | 0.00 ± 0.00 | 0.19 ± 0.13 | 0.01 ± 0.01 | 0.00 ± 0.00 | 0.05 ± 0.01 | 0.05 ± 0.02 |

Appendix II.

20-year Artr 2 – Control

20-year Artr – Disturbed



20-year Atsp – Control

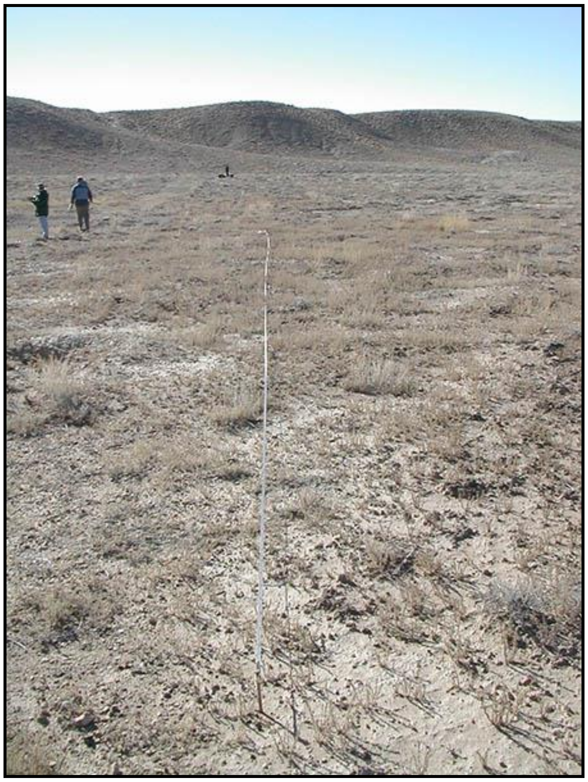
20-year Atsp – Disturbed

20-year Cora – Control

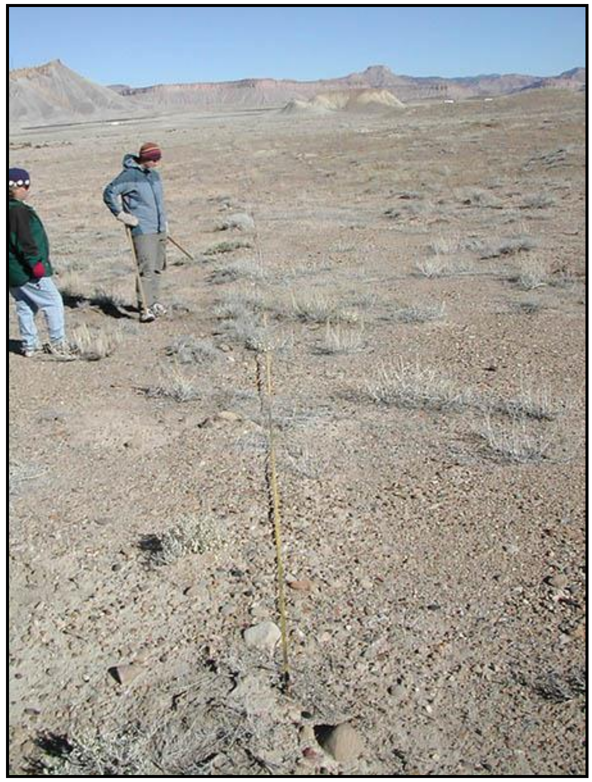
20-year Cora – Disturbed

40-year Artr – Control

40-year Artr – Disturbed



40-year Atsp – Control

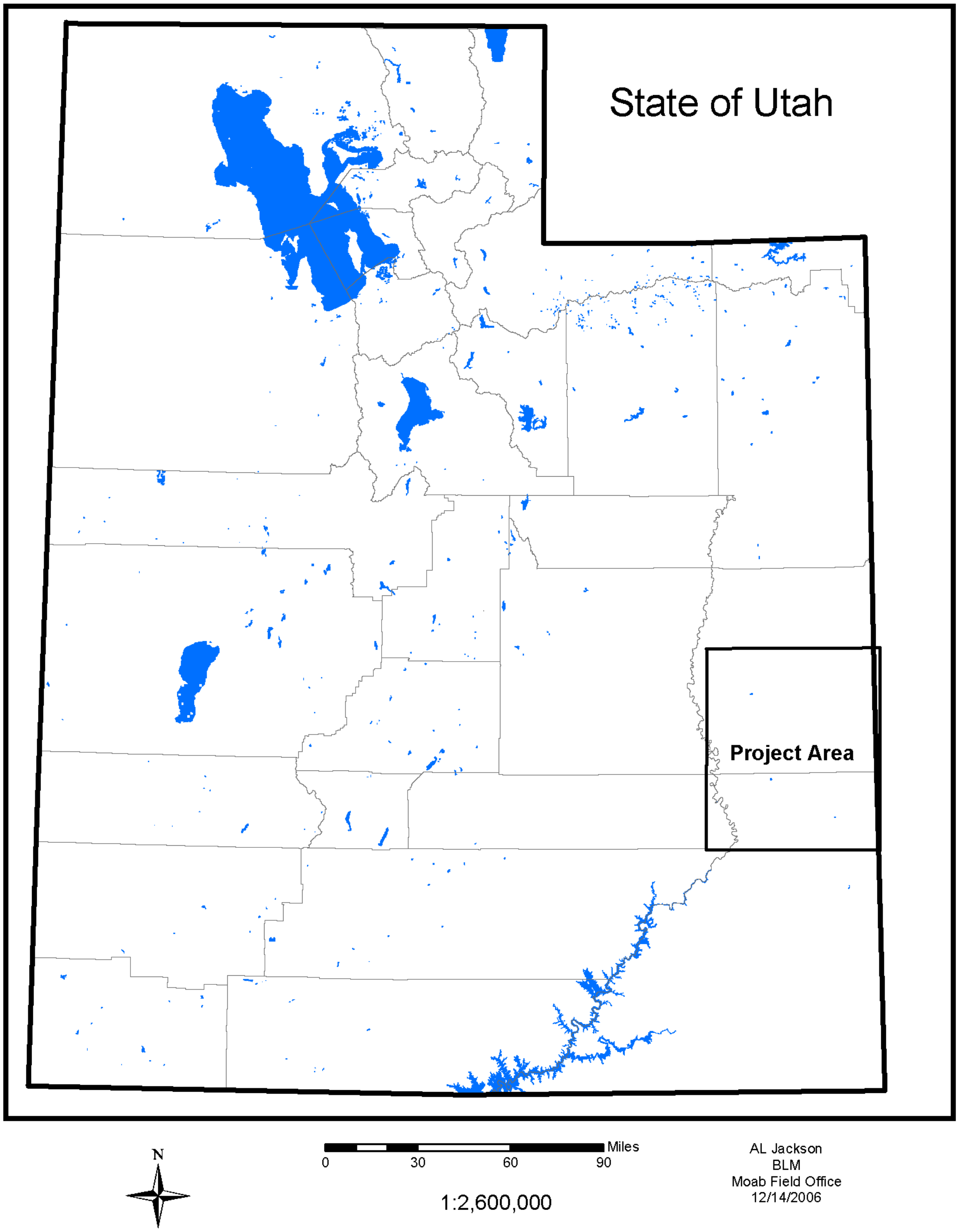


40-year Atsp – Disturbed

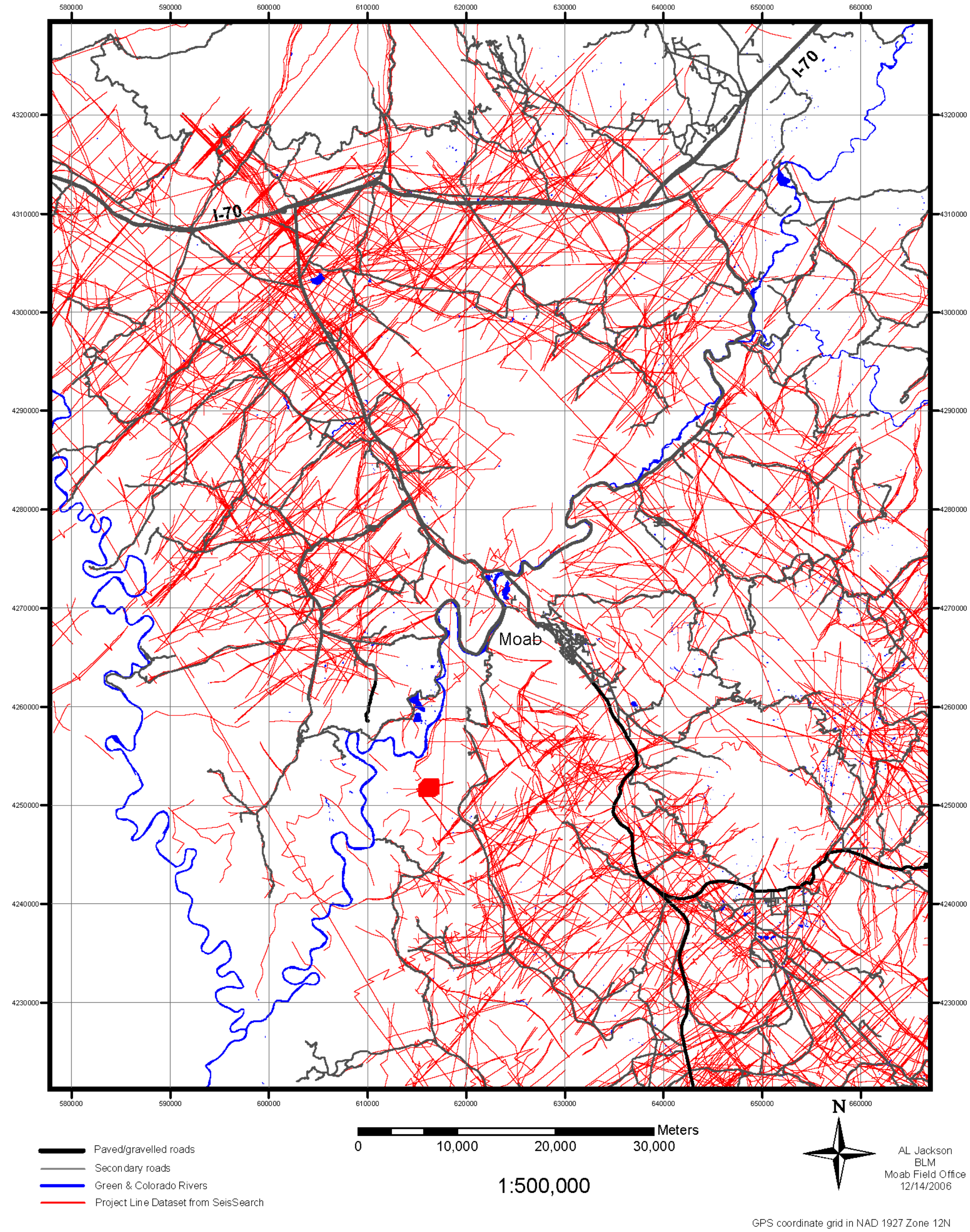
40-year Cora – Control

40-year Cora – Disturbed

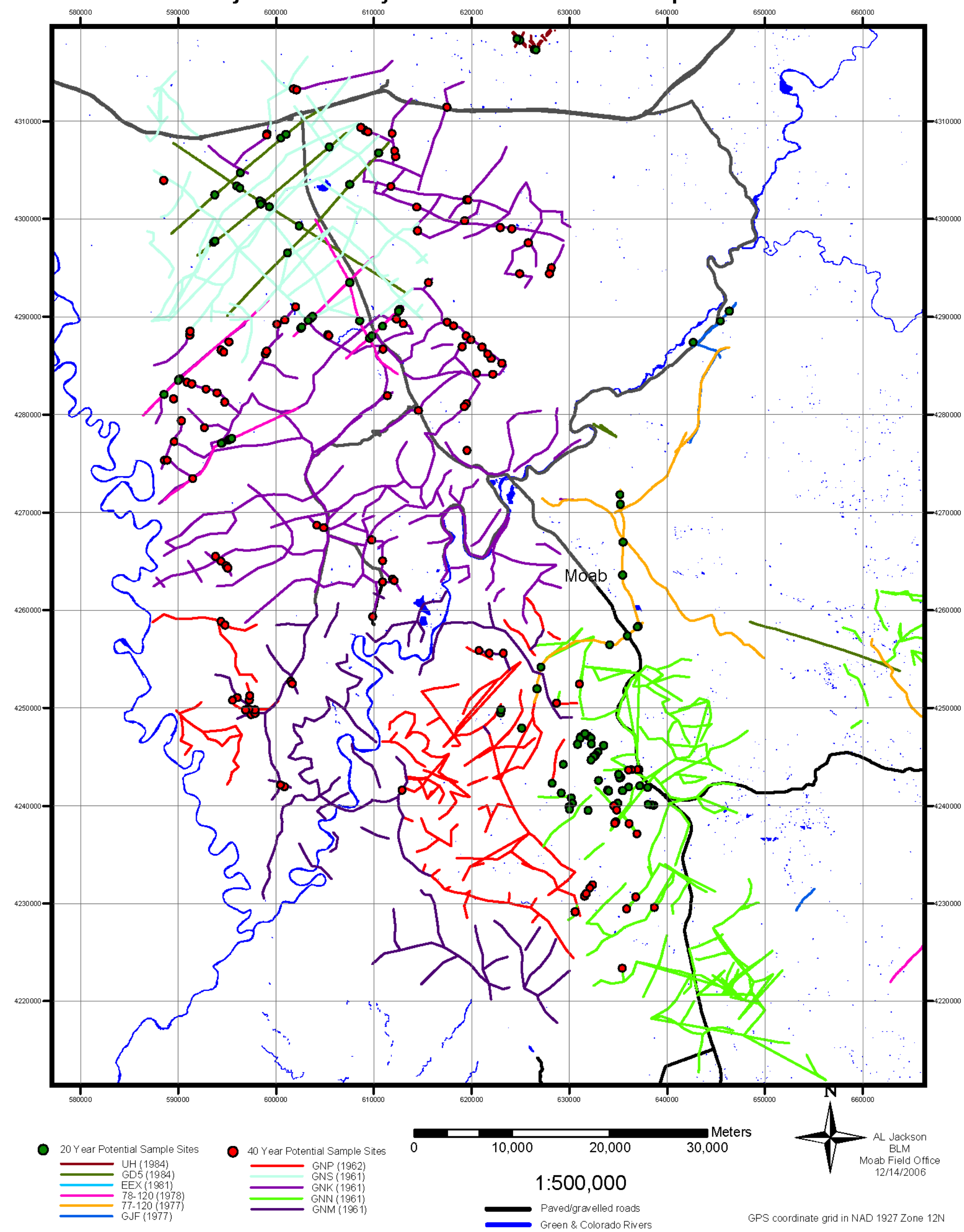
**Map No. 1 - DOE Historical Seismic Project:**
**Project Area Location**



**Map No. 2 - DOE Historical Seismic Project:**
**Complete Project Line Dataset Available**



**Map No. 3 - DOE Historical Seismic Project:**
**Project Lines Analyzed and Initial Potential Sample Sites**



## Map No. 4 - DOE Historical Seismic Project: Final Sample Locations